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PRODUCTION QUALITY ASSURANCE TESTING OF A MINUTEMAN III LGM-30G STAGE II ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE (MOTOR S/N PQA6-60)

W. D. Ervin and J. D. Gibson

ARO, Inc.

February 1973

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ENGINE TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

PRODUCTION QUALITY ASSURANCE TESTING OF A MINUTEMAN III LGM-30G STAGE II ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE (MOTOR S/N PQA6-60)

W. D. Ervin and J. D. Gibson
ARO, Inc.

FOREWORD

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC) at the request of the Space and Missile Systems Organization (SAMSO), Air Force Systems Command (AFSC), for the Aerojet Solid Propulsion Company under Program Element 11213F, System 133B.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted on November 27, 1972, under Project No. RA025, and the manuscript was submitted for publication on December 14, 1972.

This technical report has been reviewed and is approved.

CHAUNCEY D. SMITH, JR. Lt Colonel, USAF Chief Air Force Test Director, ETF Directorate of Test	A. L. COAPMAN Colonel, USAF Director of Test

ABSTRACT

LGM-30G Stage II solid-propellant rocket motor (S/N PQA6-60) was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF) on November 27, 1972, in support of the Minuteman Production Quality Assurance Test Program. Motor ballistic, liquid-injection thrust vector control system, and roll control system performances were within model specification requirements. Ignition of both the roll control and the liquid-injection thrust vector gas generators was accomplished as programmed, 3.7 sec before motor ignition at a pressure altitude of 102,000 ft. The motor was ignited at a pressure altitude of 96,000 ft. Motor ignition delay time was 109 msec. Motor action time was 64.25 sec, during which the motor produced an unaugmented vacuum total impulse of 3,950,581 lbf-sec. The unaugmented vacuum specific impulse was 287.54 lbf-sec/lbm. The liquid-injection thrust vector control and roll control systems operated as programmed throughout the firing. Postfire motor structural integrity was satisfactory with the exception that the nozzle sea-level liner had been ejected during the firing at T + 63.9 sec.

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NOMENCLATURE

AE Nozzle exit prefire area, sq in.

AT Nozzle throat prefire area, sq in.

CCW Counterclockwise

CW Clockwise

LITVC Liquid-injection thrust vector control

PC Chamber pressure, psia

RC Roll control

T Time of application of motor ignition voltage, sec

TA Motor action time, elapsed time from T to chamber pressure equal to 28 psia on the descending portion of the chamber pressure curve, sec

TGG Time of gas generator ignition, sec

SECTION I
INTRODUCTION

The purposes of the Minuteman Production Quality Assurance (PQA) Program (Ref. 1) are (1) to demonstrate that production motors meet the requirements outlined in the model specification (Ref. 2) and (2) to demonstrate reliability and reproducibility of the Stage II operational motor. The test reported herein is the thirteenth of a series of Minuteman LGM-30G Stage II motors to be fired at simulated altitude at AEDC in this program.

SECTION II
APPARATUS

2.1 TEST ARTICLE DESCRIPTION

The primary components of the LGM-30G Stage II solid-propellant rocket motor (Fig. 1, Appendix I) are a cylindrical, titanium alloy chamber loaded with ANB-3066 propellant; a single, partially submerged nozzle and nozzle extension (Fig. 2) which provides an overall expansion ratio of 24.8; and a propellant-type igniter with a safe-and-arm device. Mounted on the aft end of the chamber, surrounding the nozzle, are a secondary liquid-injection thrust vector control (LITVC) system and a hot gas roll control (RC) system. A summary of the information defining the test article configuration is presented in Table I (Appendix II).

Nominal length and case diameter of the LGM-30G Stage II motor are 162 and 52 in, respectively. The nominal gross weight of the motor is 15,600 lbm of which approximately 14,000 lbm is propellant.

The LITVC system is designed to impose pitch and yaw forces on the missile by injecting a secondary fluid into the exhaust gas stream at an area ratio of 8.36 (21.8 in. downstream of the nozzle throat). At each of the four injection points, a servocontrolled, hydraulically actuated valve (Fig. 3) with three pintles is used to control injectant flow rate. The injectant fluid, Freon® 114B2, is supplied to the four injector valves through separate supply lines connected to a toroidal storage and expulsion tank (Fig. 4) located on the aft end of the chamber. The pressurization gas is provided by a solid-propellant gas generator. System pressure is controlled by a preset, spring-operated, poppet-type relief valve which dumps the unused gas overboard through two diametrically opposed ports located on the motor aft skirt.

The motor has an additional gas generator which exhausts tangentially through two pairs of nozzles in the motor aft skirt (Fig. 5) to provide roll control. The two control valves provide equal gas flow through opposing nozzles during null periods. When a roll moment is required, flow through the appropriate nozzle in each pair is restricted by closing the valve poppet, thus producing the required moment.

2.2 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5) (Fig. 6 and Ref. 3) is a horizontal test complex for testing rocket motors with up to 100,000-lbf thrust at pressure altitudes of approximately 100,000 ft. The cell is 16 ft in diameter and 50 ft long. The cell is equipped with a temperature-conditioning system designed to maintain the test cell and motor in a prescribed temperature range from motor installation until prefire pumpdown.

The multicomponent thrust stand utilized (Fig. 7) is capable of measuring axial forces of 100,000 lbf and yaw forces of 6000 lbf. The thrust stand natural frequency for the fully loaded LGM-30G Stage II motor is approximately 25 Hz in the axial direction and 20 Hz in the yaw direction. A steam ejector-diffuser system is used in conjunction with rotating exhauster machinery to provide altitude simulation. An auxiliary steam ejector pumping system was used to remove RC and LITVC overboard dump gases from the test cell.

2.3 INSTRUMENTATION

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisition system scanning each parameter at a basic rate of 200 samples/sec and recording on magnetic tape; frequency modulation (FM) systems recording on magnetic tape; and photographically recording galvanometer-type oscillographs recording at paper speeds of 16 and 40 in./sec. Photo-optical recorders provided a permanent visual record of the firing. Table II presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix III. Uncertainties of the J-5 instrument systems are contained in Appendix IV. All digital data reduction was accomplished with an IBM 370 computer.

SECTION III
PROCEDURE

Date	Activity or Item Performed	Remarks
November 20, 1972	Motor received at AEDC; visual inspection performed	No visible damage
November 21, 1972	Electrical check, RC valve (STM-161)	Electrical check satisfactory
November 21, 1972	Installation of LITVC injector pressure transducers	
November 21, 1972	Leak test, motor case (STM-161)	Leak test satisfactory

Date	Activity or Item Performed	Remarks
November 22, 1972	Motor transferred to test cell and installed	
November 22, 1972	Safe-and-arm and ignition system check	Ignition systems verified
November 22, 1972	Leak test of LITVC injector pressure transducers	Leak test satisfactory
November 22, 1972	Completed LITVC pintle calibrations	
November 27, 1972	Motor fired	
November 27, 1972	Visual inspection performed	Motor condition satisfactory
November 28, 1972	Motor removed from test cell and transferred to the Rocket Preparation Area	
November 28, 1972	Removed AEDC-supplied transducers	
November 28, 1972	Postfire nozzle throat and exit plane diameter measurements taken	Results in Table III
November 30, 1972	Motor shipped to Aerojet/Sacramento	

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

The results reported herein were obtained from the firing of an LGM-30G Stage II motor (S/N PQA6-60) in Rocket Development Test Cell (J-5) on November 27, 1972. This was the thirteenth of a series of motors to be fired at AEDC as part of the Minuteman LGM-30G Stage II Production Quality Assurance Program. Data from this test are compared with data obtained from other tests of LGM-30G Stage II motors at AEDC. A summary of performance for these motors is presented in Table IV.

4.2 BALLISTIC PERFORMANCE

Motor ballistic performance for this motor was within the requirements of the model specification. A summary of the performance data is presented in Table V. Plots of axial

force, chamber pressure, and test cell pressure are presented in Fig. 8. The motor was temperature conditioned at 65 ± 5°F in excess of the required 60-hr minimum. Propellant grain temperature at the time of ignition was 67°F. A summary of storage and conditioning temperatures is presented in Table VI.

4.2.1 Motor Ignition

The motor was successfully ignited at a pressure altitude of 96,000 ft (geometric pressure altitude, Z, Ref. 4). A time history of igniter pressure during motor ignition is presented in Fig. 9. Igniter delay time (defined as the time required from application of ignition voltage until igniter pressure reaches 750 psia) was 11 msec which was within the maximum specification limit of 18 msec (Ref. 5). The recorded maximum and average igniter pressures were 1102 and 1031 psia, respectively, and the igniter pressure integral was 276.4 psia-sec. These pressure values were within specification.

Motor ignition delay (defined as the time from application of ignition voltage until chamber pressure reaches 371 psia) was 109 msec. This was well within the specification maximum limit of 250 msec. Motor chamber pressure during the ignition transient is compared to the specification envelope in Fig. 10. The pressure remained within the limits of the envelope.

4.2.2 Combustion Chamber Pressure

Motor action time, defined as the time from the application of ignition voltage until the chamber pressure drops to 28 psia, was 64.25 sec. Average combustion chamber pressure during motor action time was 469 psia. The maximum operating chamber pressure achieved during the firing was 538 psia, which is less than the 570-psia maximum limit. Measured chamber pressure during motor operation is compared with the manufacturer's predicted chamber pressure (Ref. 6) and the specification limit in Fig. 11. Chamber pressure during motor tailoff is compared with its specification envelope in Fig. 12. The pressure remained within limits.

4.2.3 Axial Thrust and Thrust Coefficient

Vacuum-corrected thrust was within model specification limits for a motor temperature conditioned at 60 to 70°F and is presented with the manufacturer's predicted thrust (Ref. 6) and the specification envelope in Fig. 13. Average unaugmented vacuum-corrected thrust over motor action time was 61,488 lbf, which is within the 53,900-lbf minimum and 64,000-lbf maximum prescribed. Thrust decay time during tailoff, defined as the time required for vacuum thrust at 80°F to decay from 41,000 to 2000 lbf, was 1.80 sec. This time was within the limits of 1.48 to 3.54 sec. Vacuum thrust during motor tailoff is compared with its specification envelope in Fig. 14. Thrust remained within the tailoff limits.

The average thrust coefficient during motor action time, excluding thrust augmentation, was determined from vacuum-corrected total impulse, integral of chamber

pressure corrected to stagnation conditions at the nozzle entrance, and a calculated throat area. The average thrust coefficient calculated for this motor was 1.797.

4.2.4 Impulse

Measured total impulse during motor action time, including thrust augmentation, was 3,938,377 lbf-sec. Measured total impulse during motor action time, excluding thrust augmentation, was 3,929,791 lbf-sec. Total impulse corrected to vacuum conditions was obtained by adding the product of the cell pressure integral and prefire nozzle exit area to the measured total impulse. This vacuum correction was approximately 0.5 percent of the measured total impulse. The vacuum total impulse during action time, including thrust augmentation, was 3,959,167 lbf-sec. The vacuum total impulse during action time, excluding thrust augmentation, was 3,950,581 lbf-sec, which is greater than the 3,907,000-lbf-sec minimum requirement for this parameter from the model specification (Ref. 2). Vacuum specific impulse for this motor was 287.54 lbf-sec/lbm. These parameters were calculated by the methods presented in Appendix V.

4.2.5 Motor Propellant Flow Rate

Average exhaust gas mass flow rate during action time was 213.7 lbm/sec. A plot of exhaust gas mass flow rate during motor operation is presented in Fig. 15. The flow rate calculation was performed utilizing the equation presented in Appendix V.

4.3 ROLL CONTROL AND LIQUID-INJECTION THRUST VECTOR CONTROL SYSTEMS PERFORMANCE

4.3.1 Roll Control System

The RC gas generator was successfully ignited as programmed, 3.7 sec before motor ignition at a pressure altitude of 102,000 ft. A time history of RC gas generator pressure during its operation is presented in Fig. 16 and is compared to the model specification limits. The pressure remained within the limits with the maximum being 2091 psia. The RC system duty cycle is shown in Table VII. Roll moments were realized at the programmed times with all valve response times well within the limits given in the model specifications. Valve response times were determined from nozzle pressure differential measurements on the RC valves. A summary of the RC system performance is included in Table V.

4.3.2 Liquid-Injection Thrust Vector Control System

The LITVC system gas generator was successfully ignited as programmed, 3.7 sec before main motor ignition at a pressure altitude of 102,000 ft. The maximum interval from LITVC gas generator ignition voltage application until the first indication of pressure in the injector cavities was 105 msec, which is within the specified maximum of 880 msec. The time from LITVC gas generator ignition until attainment of 500-psia Freon

manifold pressure was 210 msec. Since the Freon tank pressure would equal or exceed the manifold pressure, this would indicate that 500 psia was reached in the tank within the 950-msec maximum defined in the model specification.

The four LITVC servoinjector valves were calibrated with Freon 114B2 at the valve manufacturer's flow calibration facility before installation on the motor. Tabulations of these calibration values, together with the results from the pintle position transducer calibrations, were used for reduction of the LITVC firing data at AEDC by the method presented in Appendix V.

Pintle position, injectant flow rate, and injector cavity pressure during the firing are presented in Figs. 17 through 20. The injector valve command voltages were satisfactorily programmed throughout the firing, and the injector valves responded as programmed. Valve 4 did require approximately 30 msec longer than normal to reach full open during the 2 to 3 sec step. This delay was attributable to the hydraulic supply pressure being 360 psia during the test instead of the required 425 ± 25 psia. However, the low pressure apparently did not affect system operation as the desired injectant flow rates were realized and system performance was normal. The LITVC duty cycle is presented in Table VIII. The Freon supply was depleted at T + 106.9 sec as indicated by the rapid decrease in Freon injectant pressure at that time. Freon manifold pressure is presented in Fig. 21. The pressure in the injector cavities, as a function of injectant flow rate, is shown in Fig. 22 to be above the minimum limit set in the specification.

The resultant yaw force during motor operating time (Fig. 23) indicates that thrust vectoring occurred as programmed. The average resultant yaw force recorded during the full-open secondary injection step (from T + 2 to T + 3 sec) was 4428 lbf, which exceeded the 3800-lbf minimum yaw force capability required during the period from T + 0.250 to T + 3 sec. An injectant flow rate of 60.9 lbm/sec was obtained during the full-open step. A thrust vector angle of 2.31 deg was produced during the period from T + 52 to T + 53 sec for an injectant flow rate of 26.5 lbm/sec, which exceeded the minimum thrust vector angle capability (2.0 deg) required from T + 3 sec until the end of motor action time or depletion of injectant as set forth in the model specification. The LITVC system performance is summarized in Table IX.

4.4 MOTOR STRUCTURAL INTEGRITY

Water quench of the motor was initiated at T + 65 sec. Visual postfire inspection revealed the motor to be in excellent condition (Fig. 24). No cork unbonding from the case was observed on this motor. The nozzle sea-level liner was ejected at T + 63.9 sec.

SECTION V
SUMMARY OF RESULTS

The results of firing an LGM-30G Stage II Production Quality Assurance motor (S/N PQA6-60) at an average pressure altitude of 98,000 ft are summarized as follows:

1. All motor ballistic and component performance data from this firing conformed to model specification requirements for the LGM-30G Stage II propulsion subsystem.

2. The motor was ignited at an altitude of 96,000 ft. The ignition delay was 109 msec, which was well within the 250-msec maximum stated in the model specification.

3. Vacuum-corrected total impulse was 3,950,581 lbf-sec (excluding augmentation), which exceeded the required minimum of 3,907,000 lbf-sec. Vacuum specific impulse was 287.54 lbf-sec/lbm.

4. The LITVC system produced a resultant yaw force of 4428 lbf during the time period from T + 2 to T + 3 sec, which was greater than the 3800-lbf minimum model specification requirement. During the period from T + 52 to T + 53 sec a thrust vector angle of 2.31 deg was produced, which exceeded the 2-deg minimum capability required by the model specification.

5. The RC system operated satisfactorily throughout the firing.

6. The nozzle sea-level liner was ejected at T + 63.9 sec.

7. The postfire structural condition of the motor was good.

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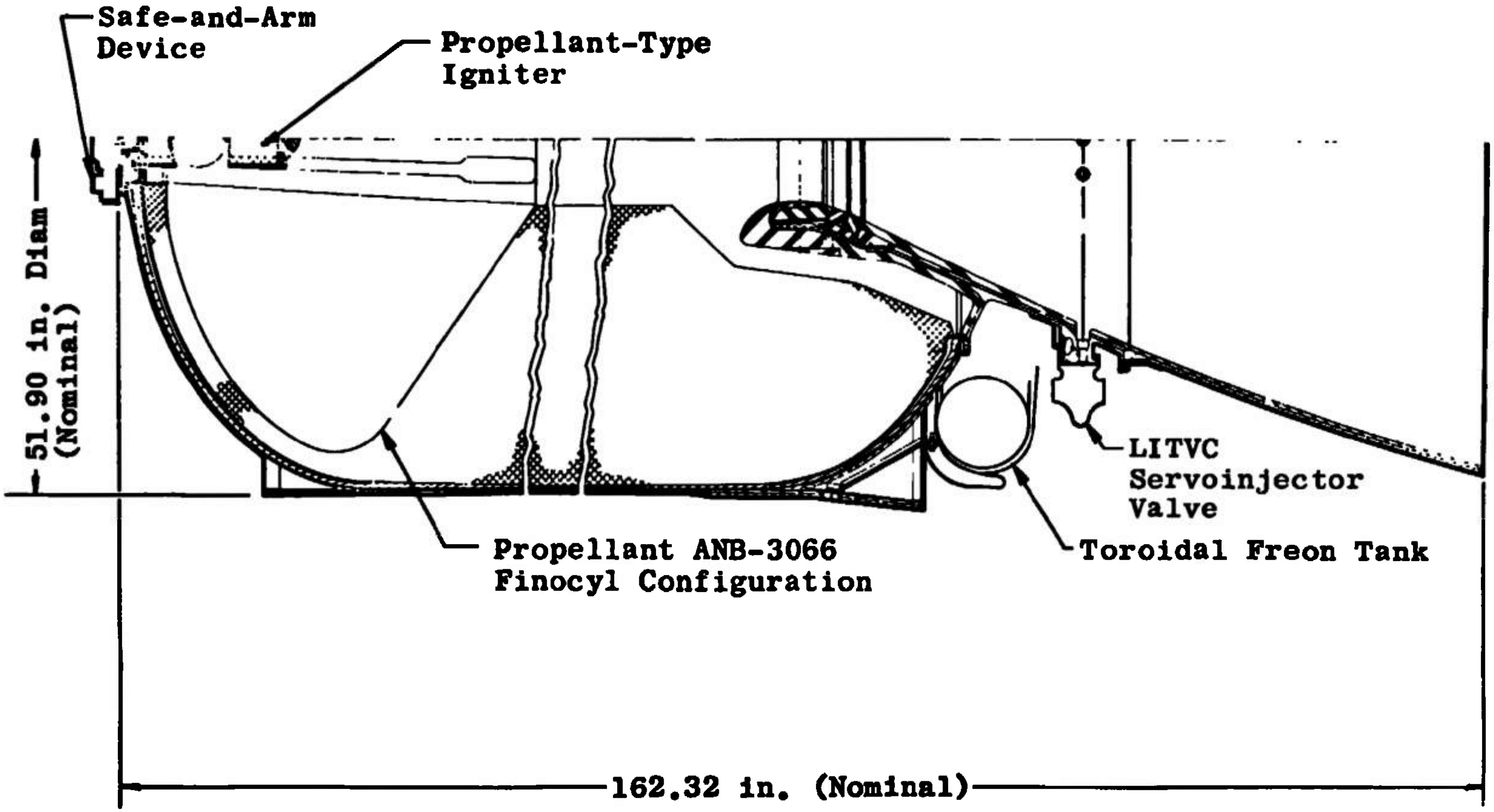
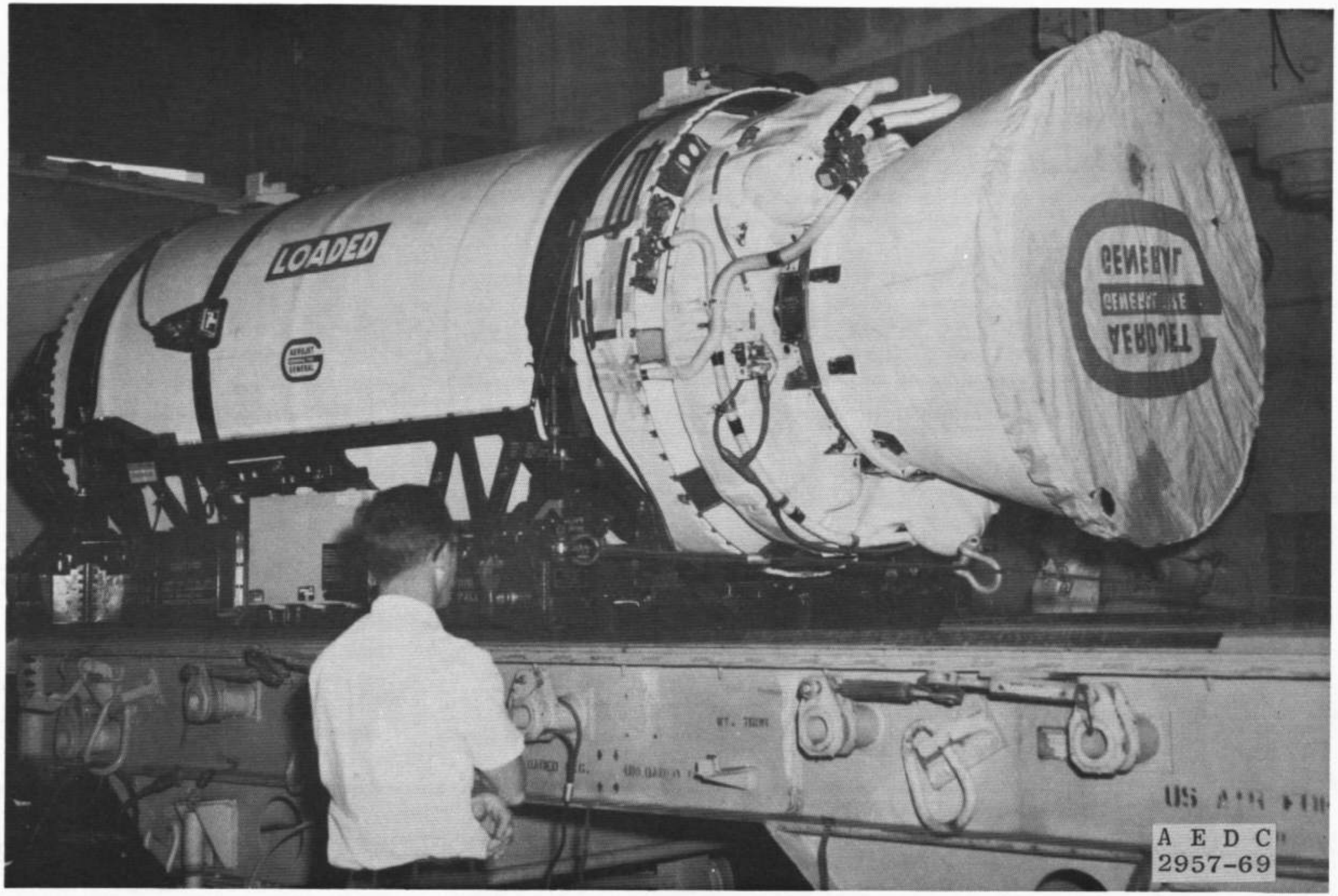
6. Aerojet Solid Propulsion Company. "Minuteman Second Stage Wing VI Rocket Motor Assembly Log." Motor S/N PQA6-60, November 10, 1972.

APPENDIXES

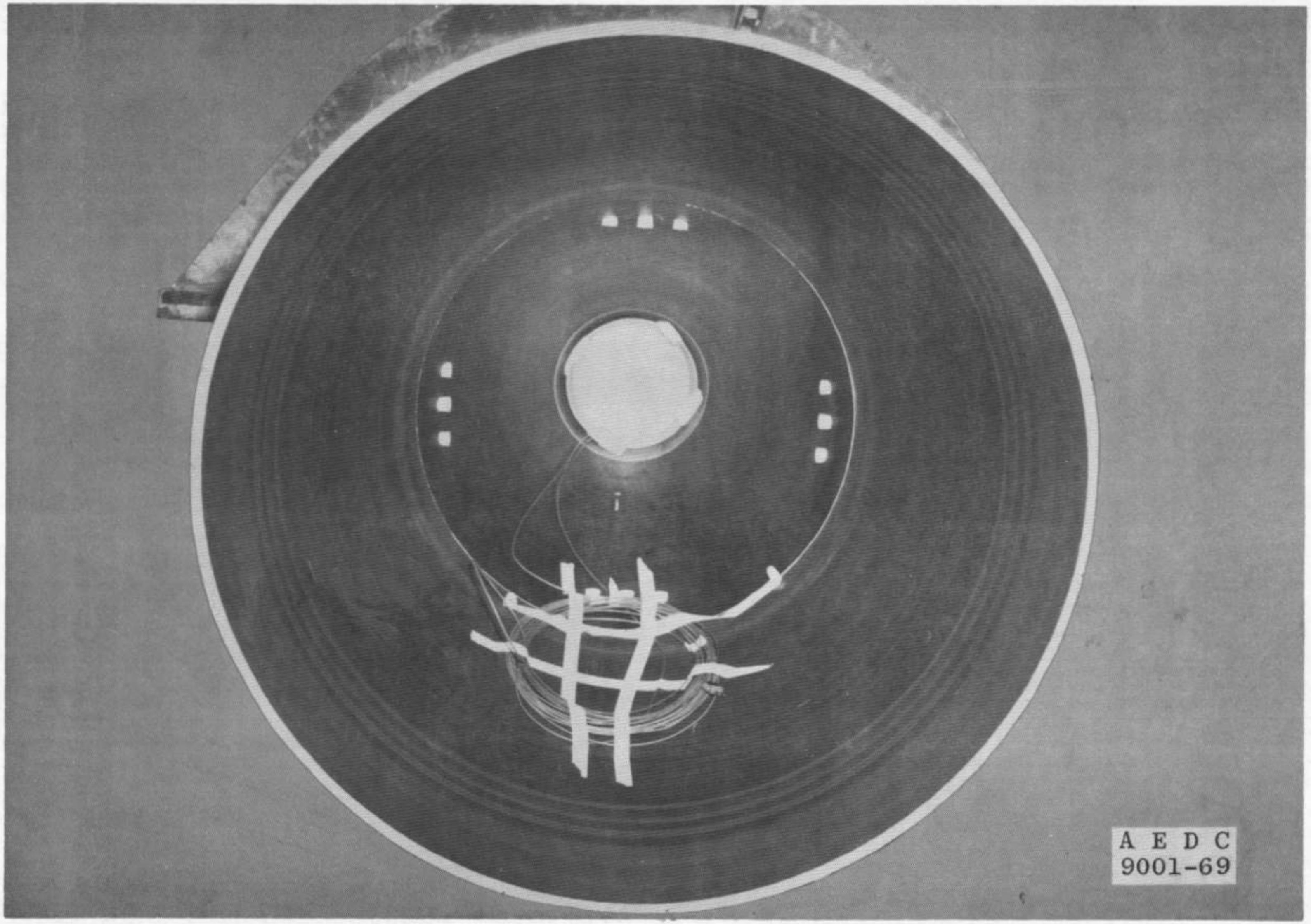
I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION CALIBRATIONS
IV. UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS
V. METHODS OF CALCULATION



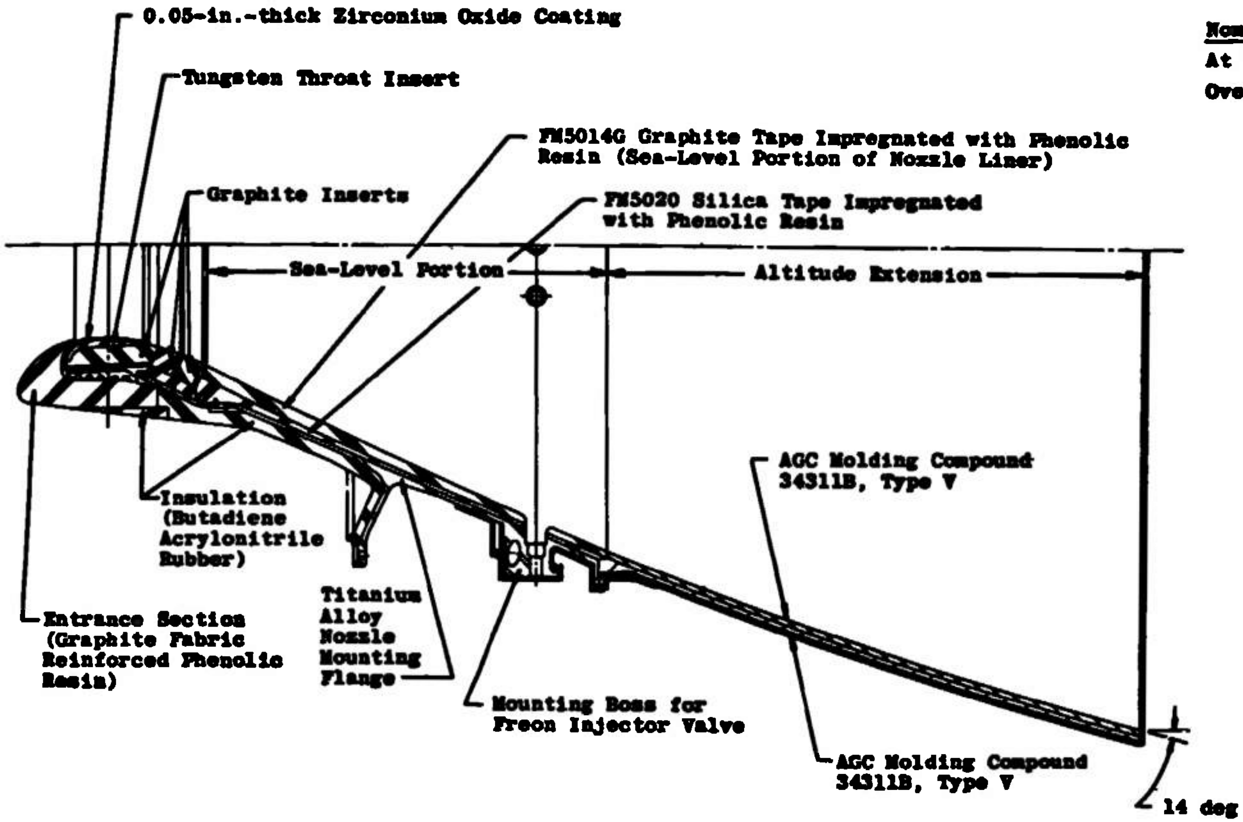
a. Quarter Section
Fig. 1 Minuteman LGM-30G Stage II Motor



b. . Overall View of Typical Motor, Prefire
Fig. 1 Continued



c. Typical Nozzle, Prefire
Fig. 1 Concluded



Nominal Area Ratio (AE/AT)	
At Injection Plane	8.36
Overall	24.8

Length from Nozzle Throat, in.	Radius, in.
4.374	5.867
6.678	7.025
8.996	8.157
11.325	9.264
13.667	10.344
16.021	11.398
18.386	12.428
20.763	13.427
23.151	14.402
25.549	15.350
27.958	16.271
30.378	17.166
32.806	18.033
35.245	18.873
37.692	19.684
40.149	20.472
42.614	21.230
45.088	21.961
47.569	22.864
50.058	23.339
52.555	23.987

Fig. 2 Nozzle Assembly

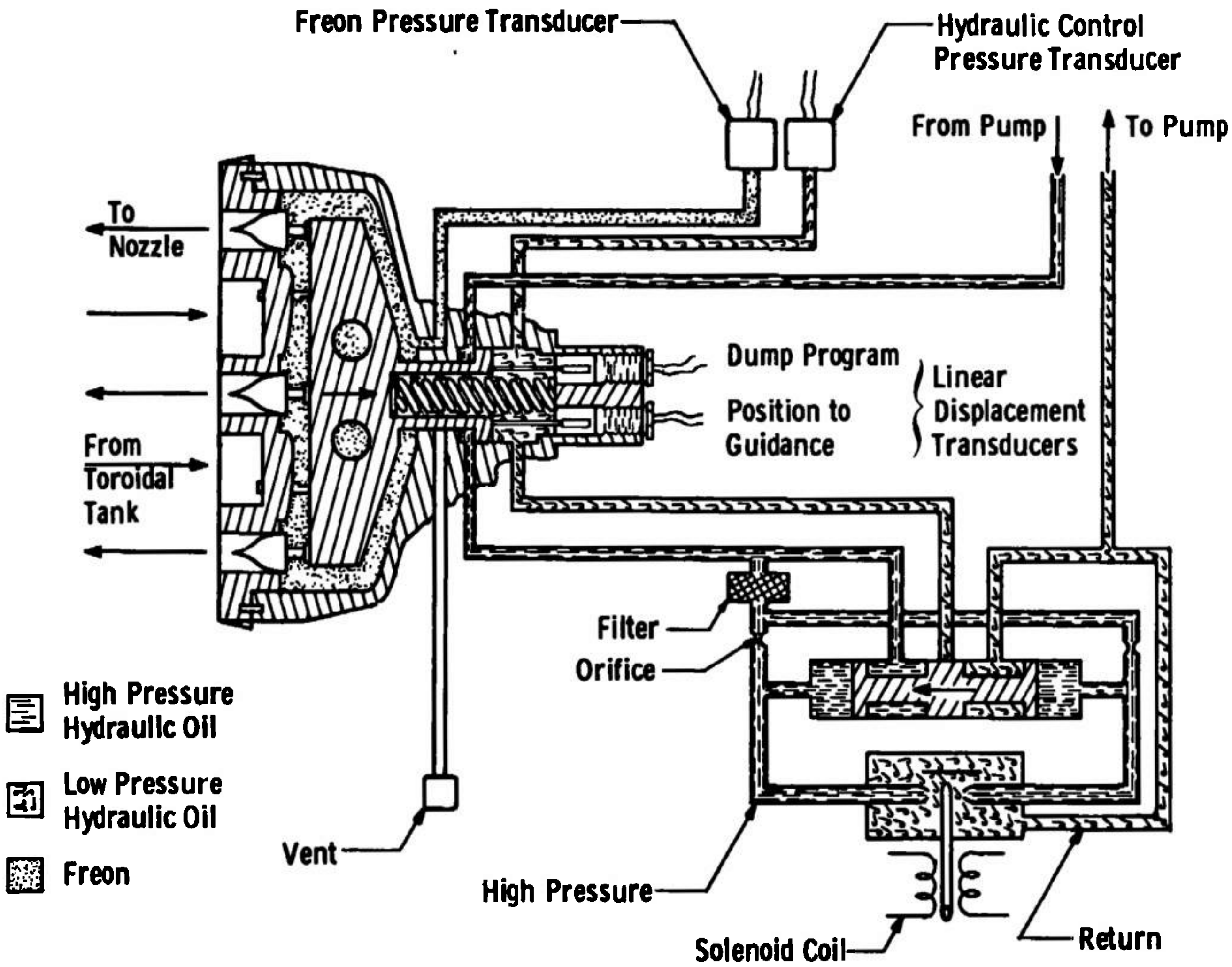


Fig. 3 Liquid-Injection Thrust Vector Control System

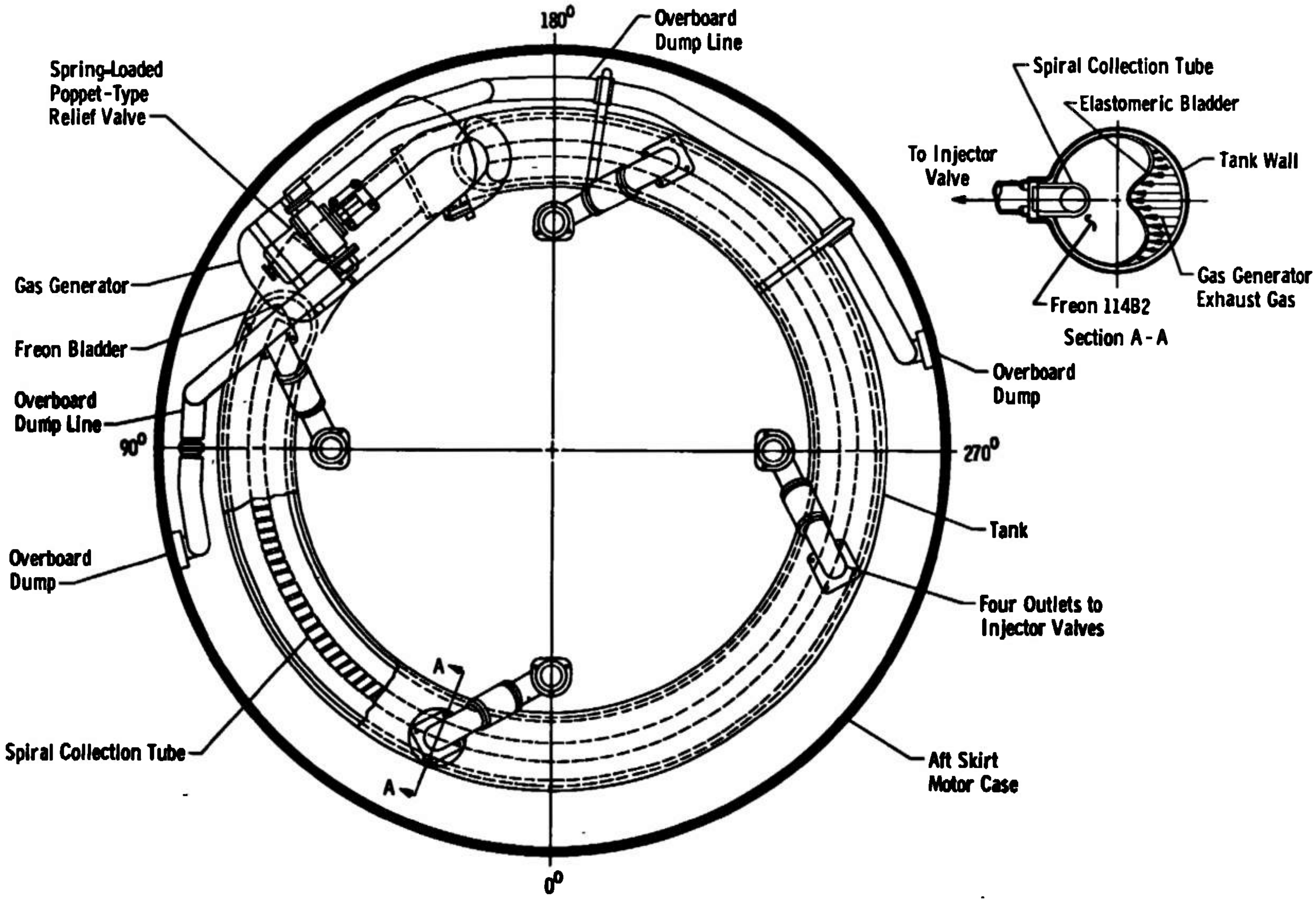


Fig. 4 Schematic of Liquid-Injection Thrust Vector Control System

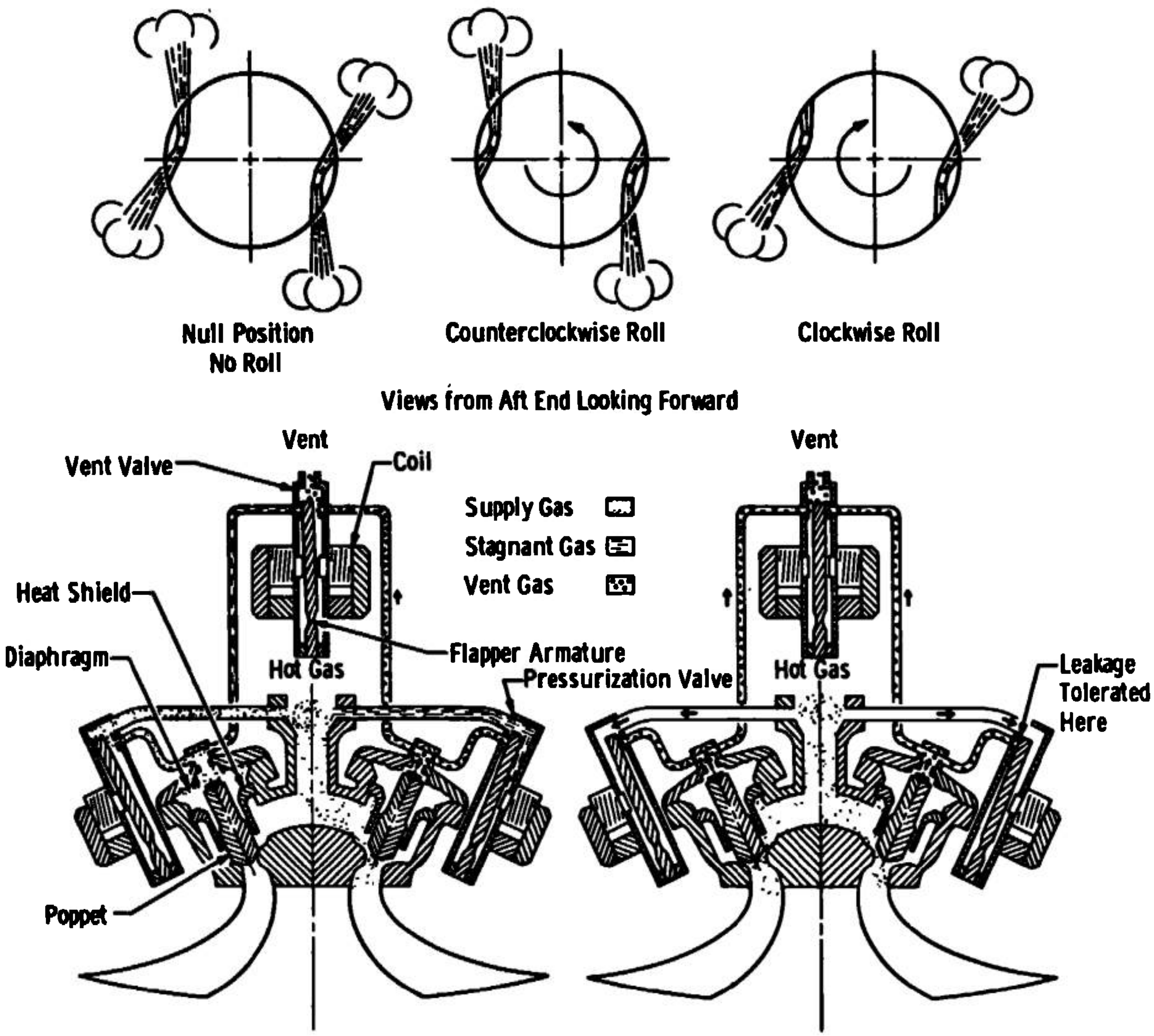


Fig. 5 Roll Control System

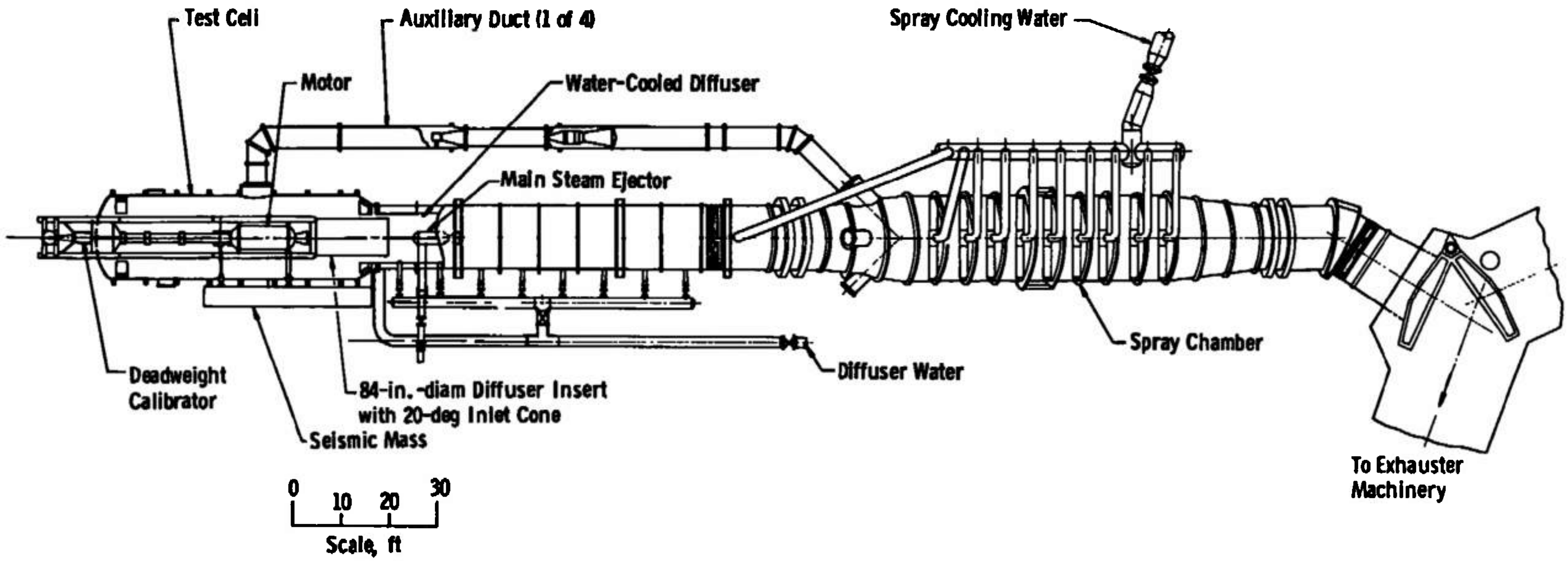


Fig. 6 Rocket Development Test Cell J-5

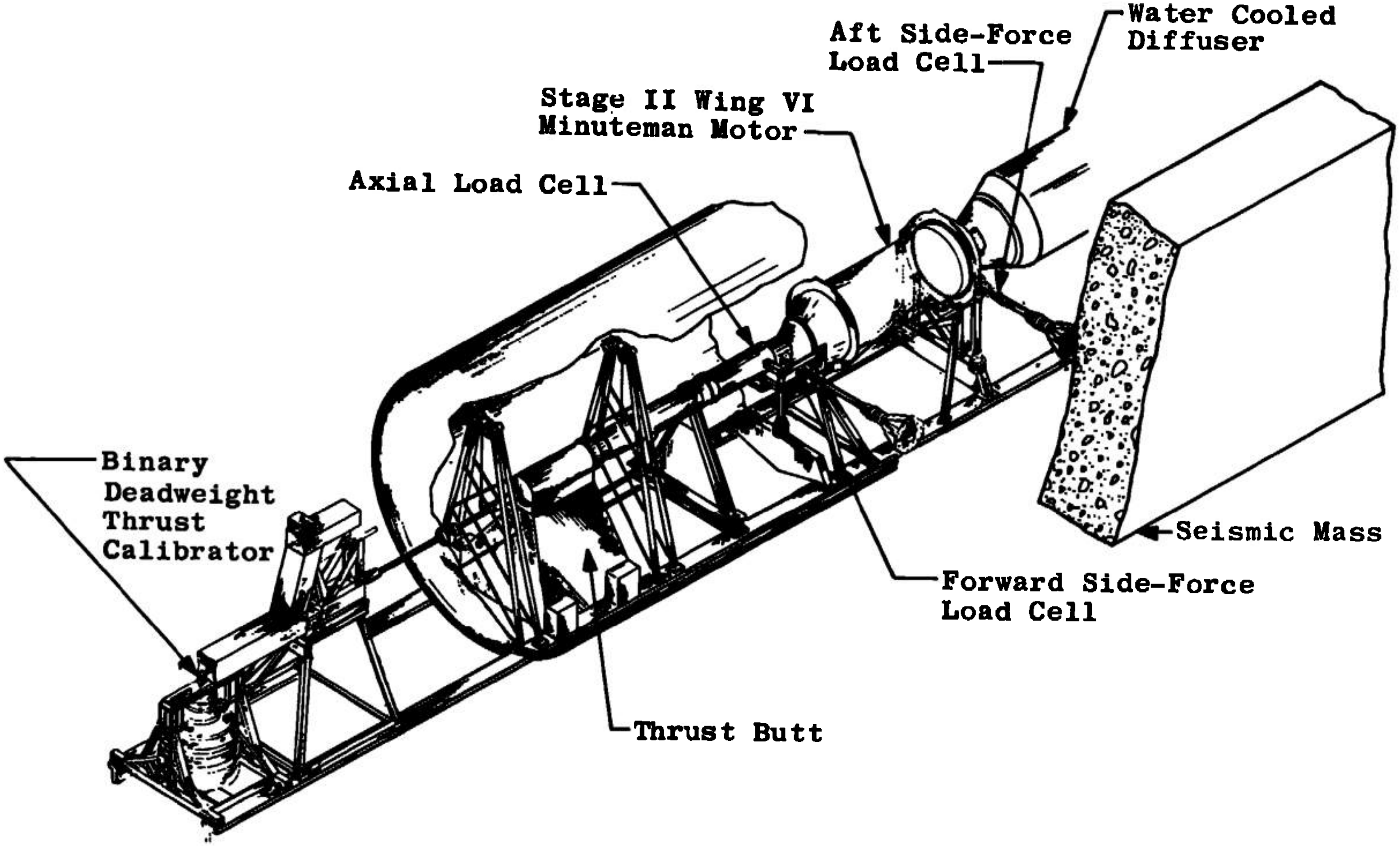


Fig. 7 Schematic of Thrust Stand

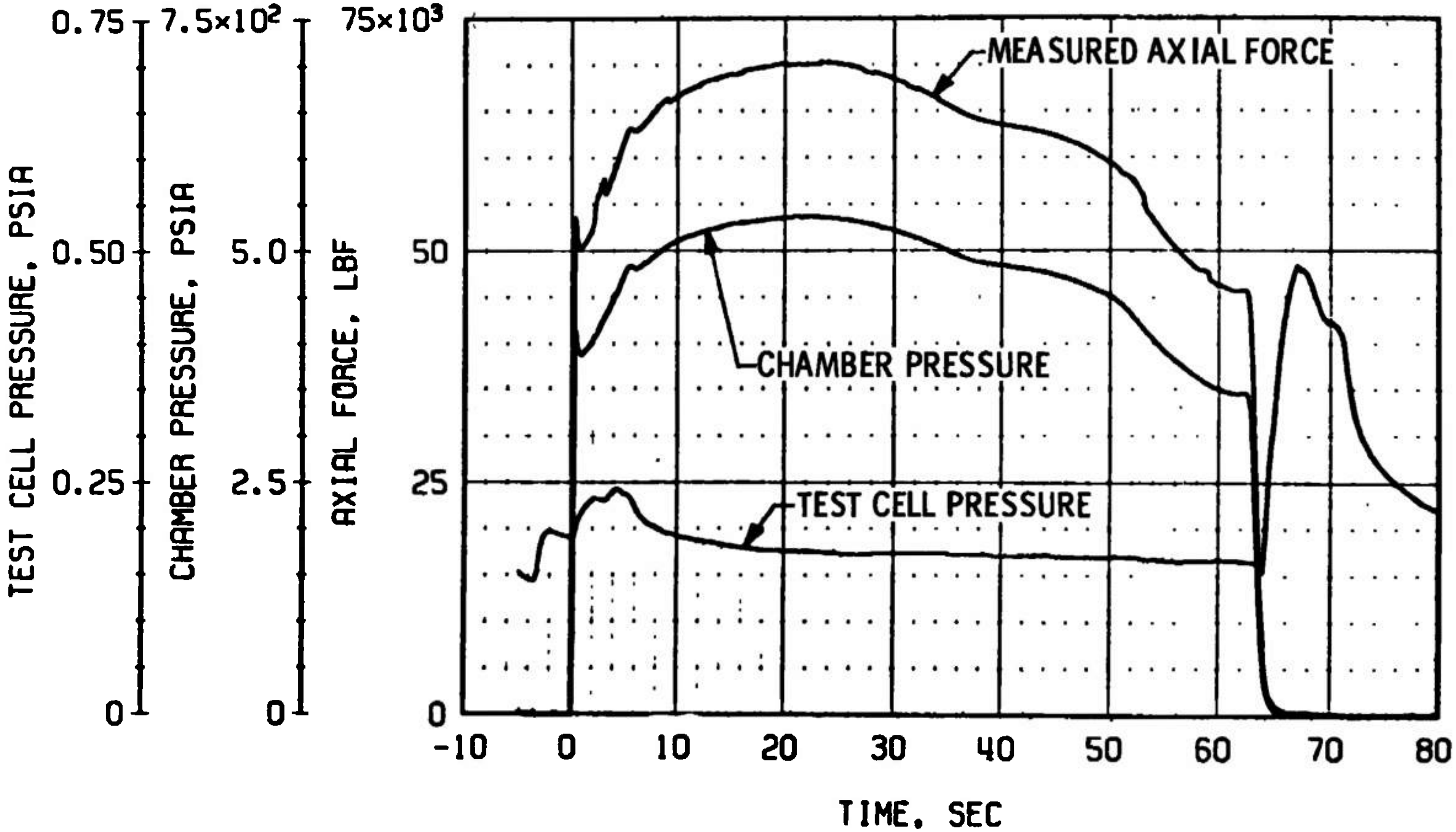


Fig. 8 Measured Axial Force, Chamber Pressure, and Test Cell Pressure during Motor Operation

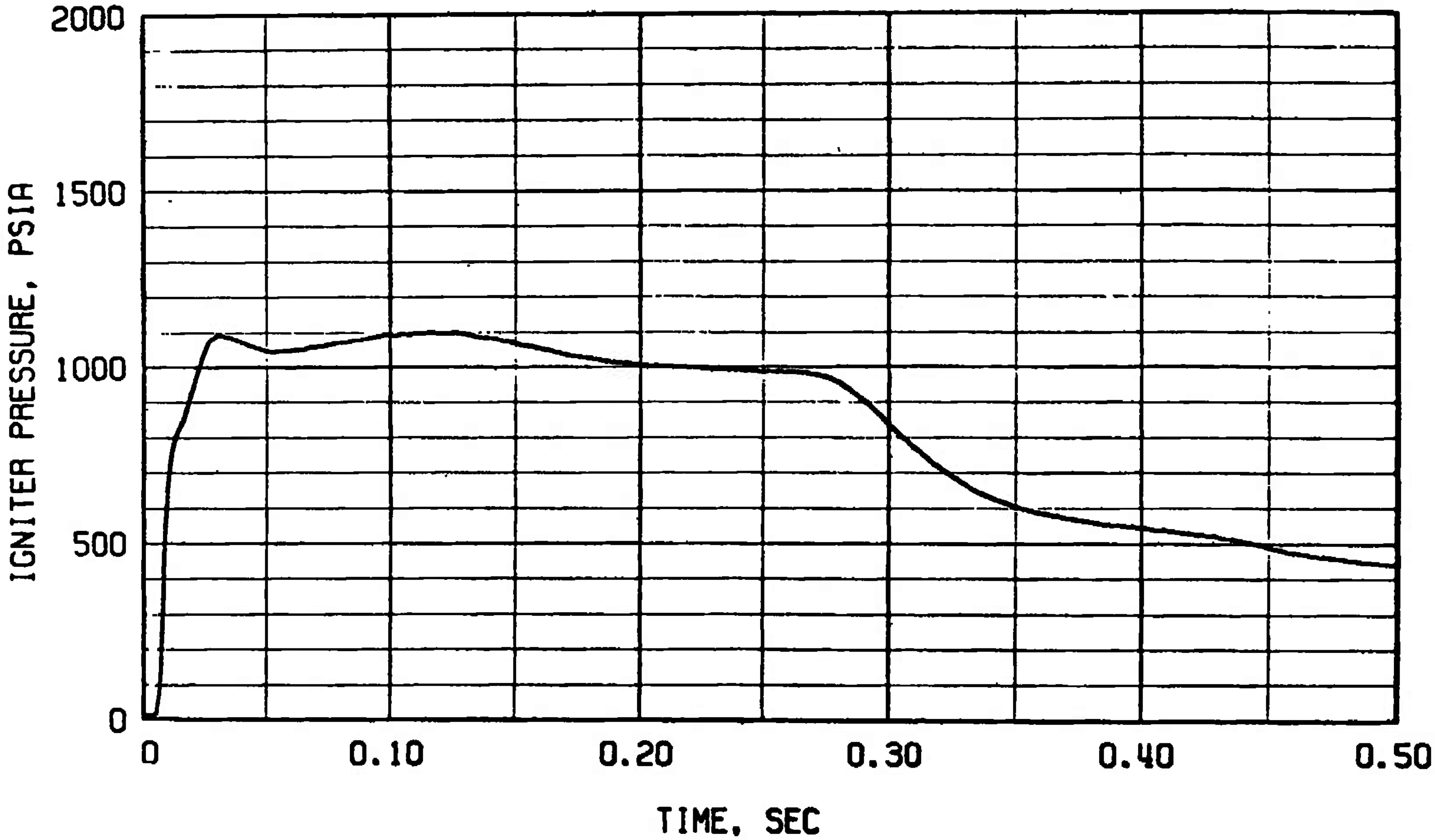


Fig. 9 Igniter Pressure during Ignition Transient

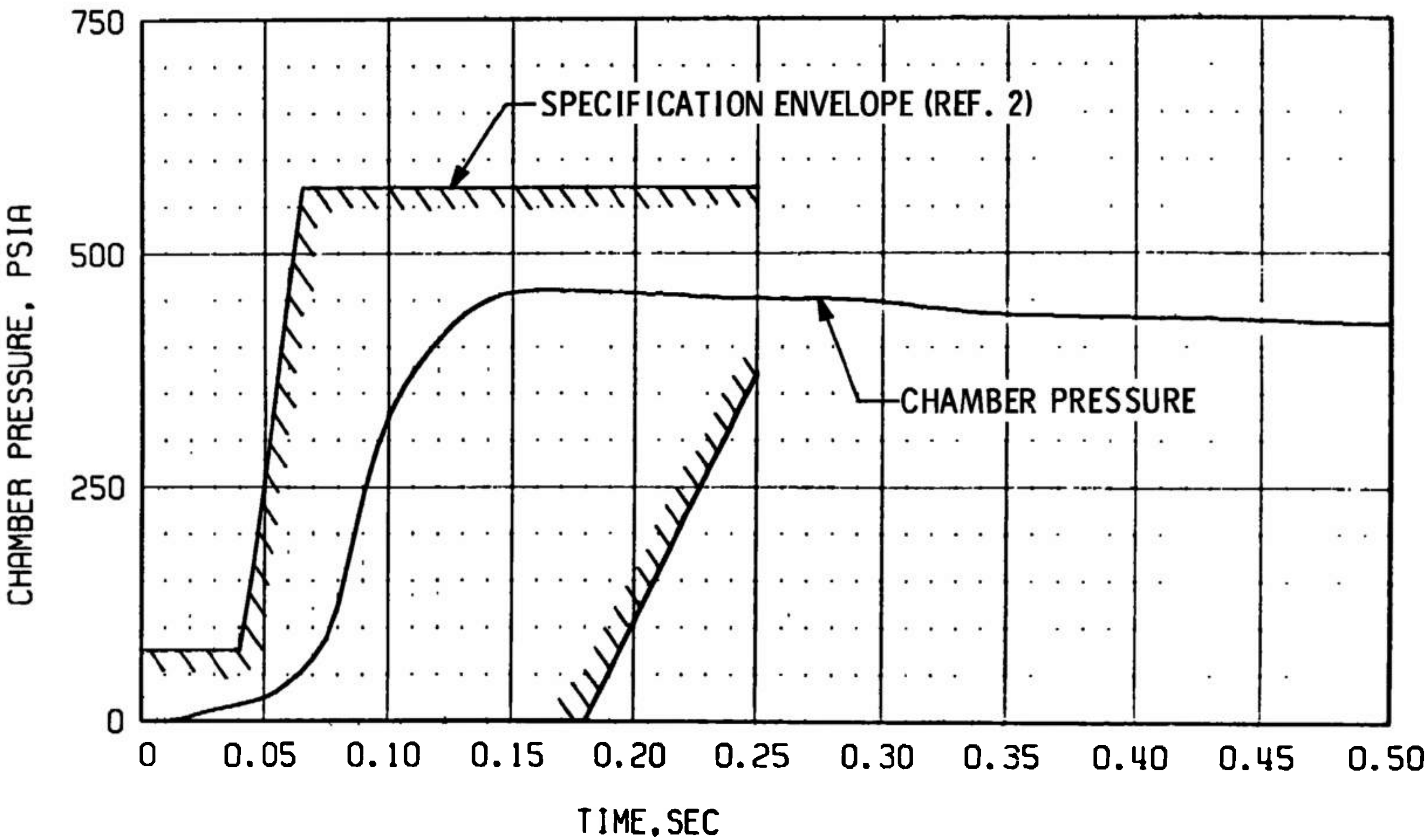


Fig. 10 Chamber Pressure during Ignition Transient

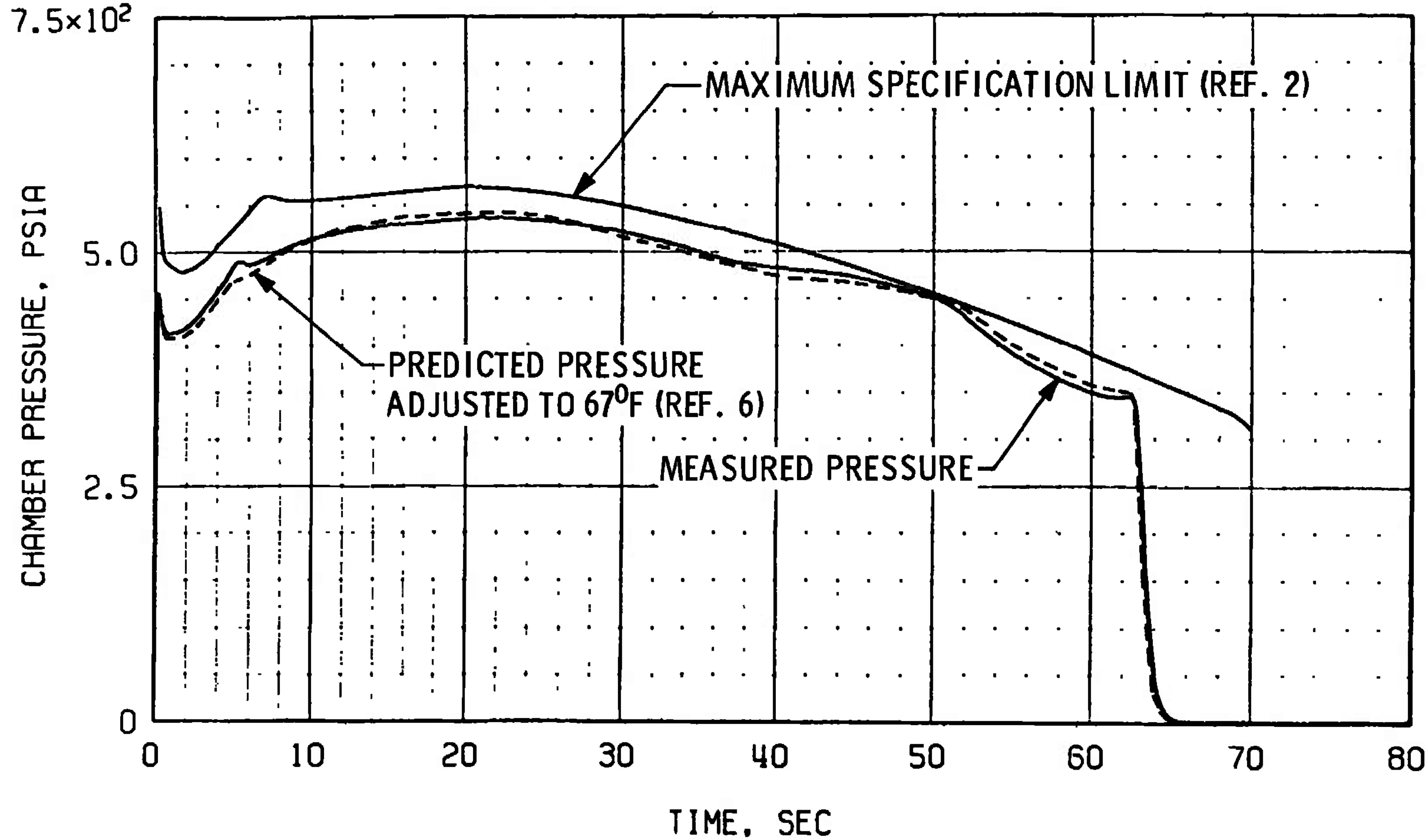


Fig. 11 Chamber Pressure; Measured, Predicted, and Maximum Specification

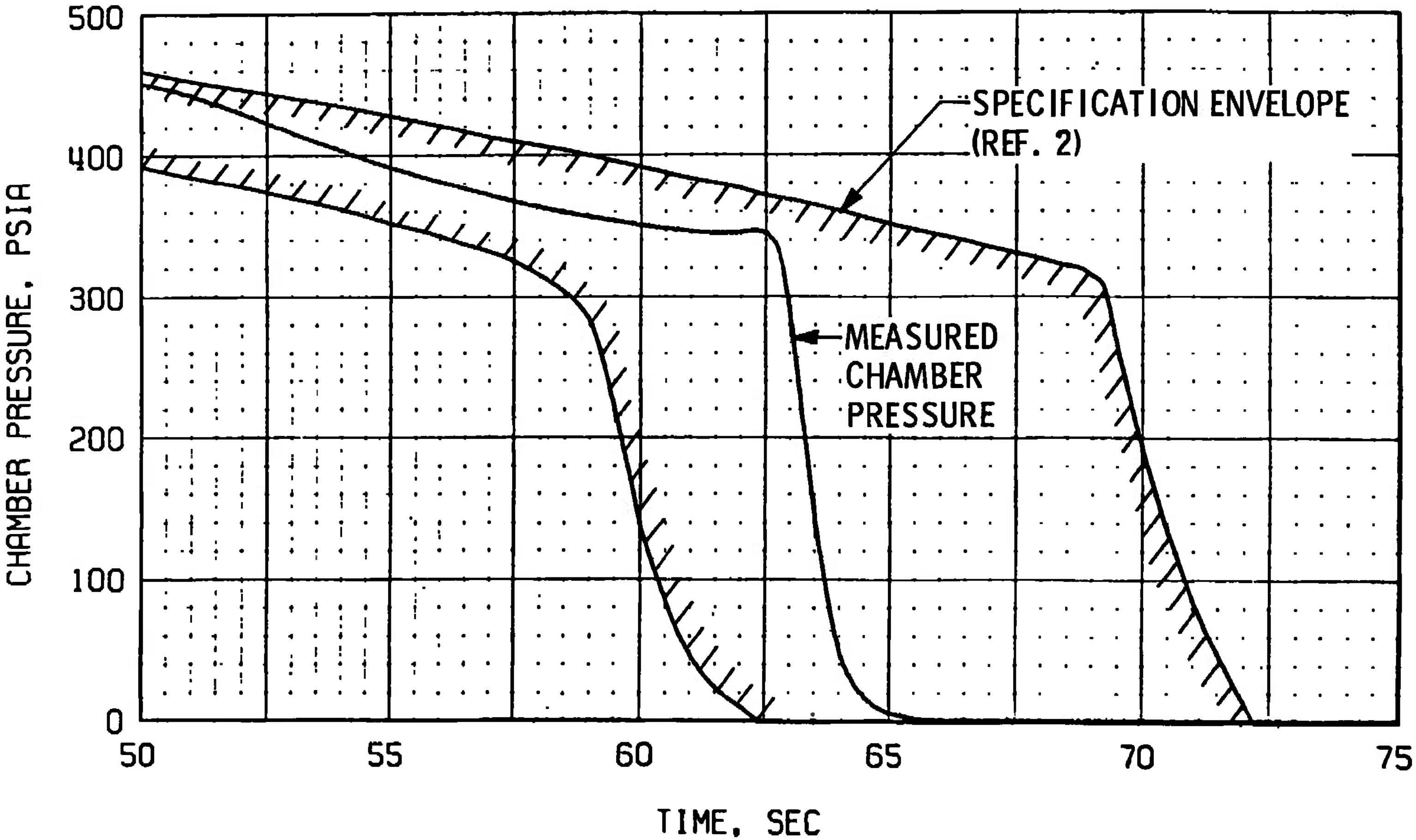


Fig. 12 Chamber Pressure Decay and Specification Envelope

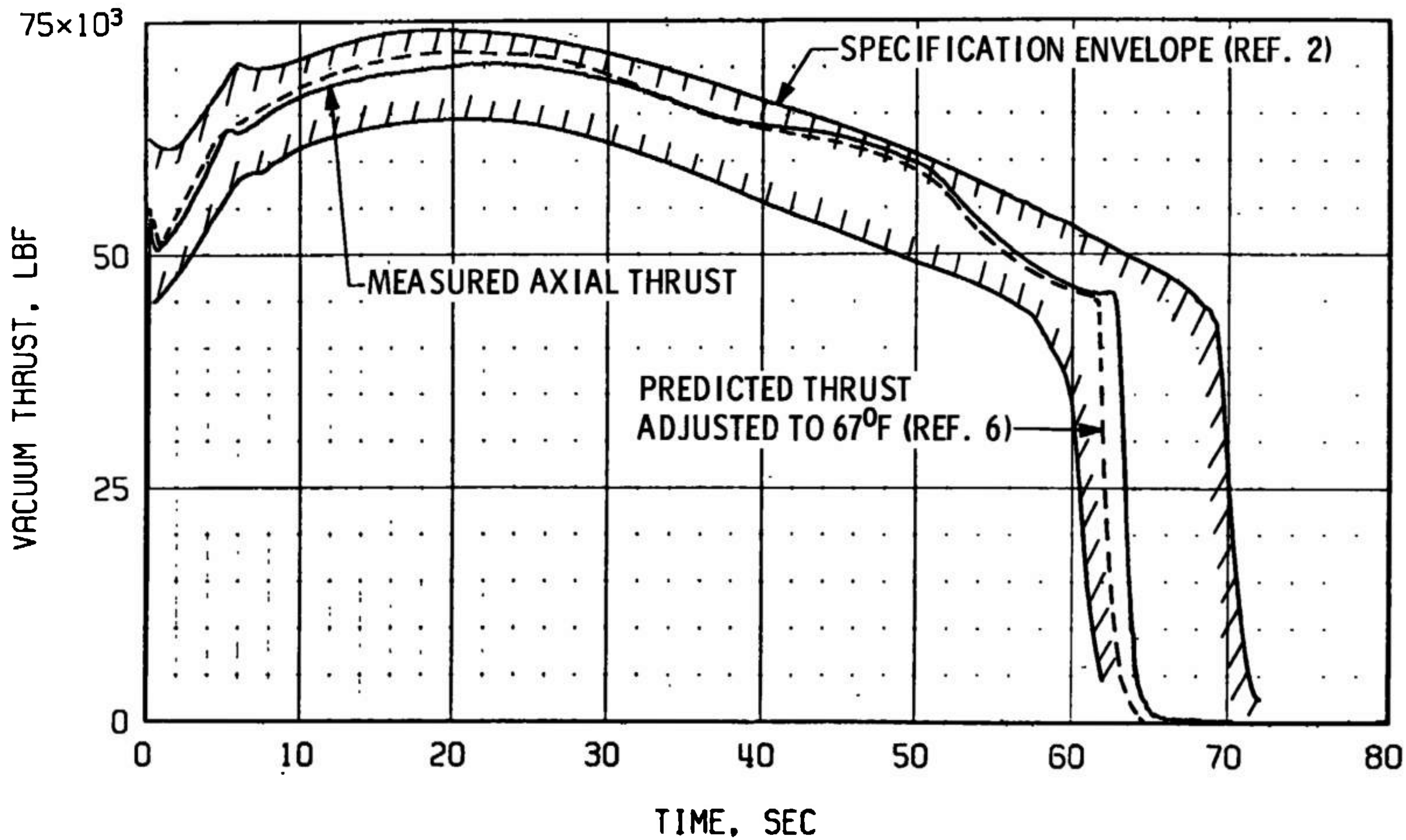


Fig. 13 Vacuum Thrust; Measured Axial, Predicted, and Specification Envelope

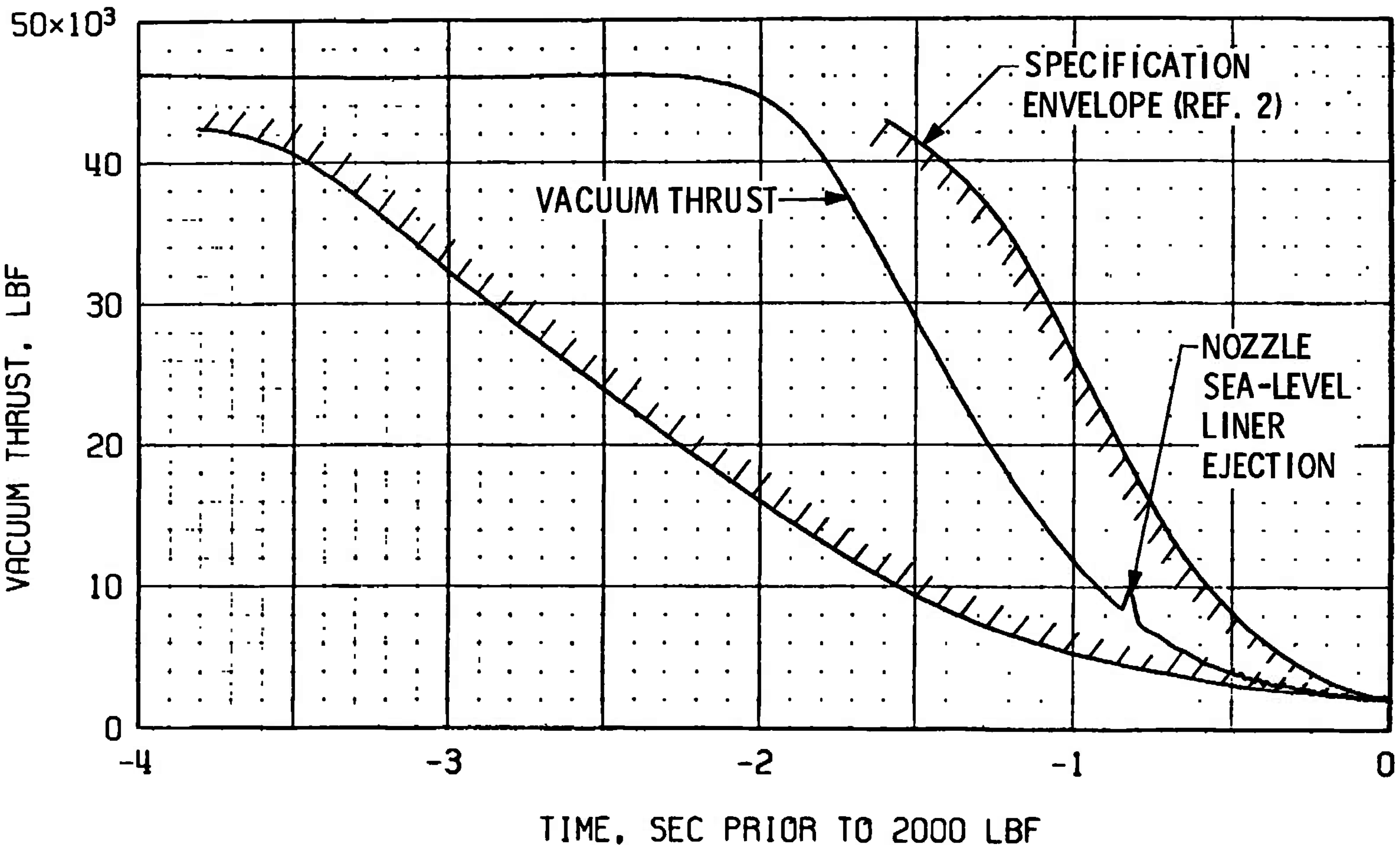


Fig. 14 Vacuum Thrust Tailoff and Specification Envelope

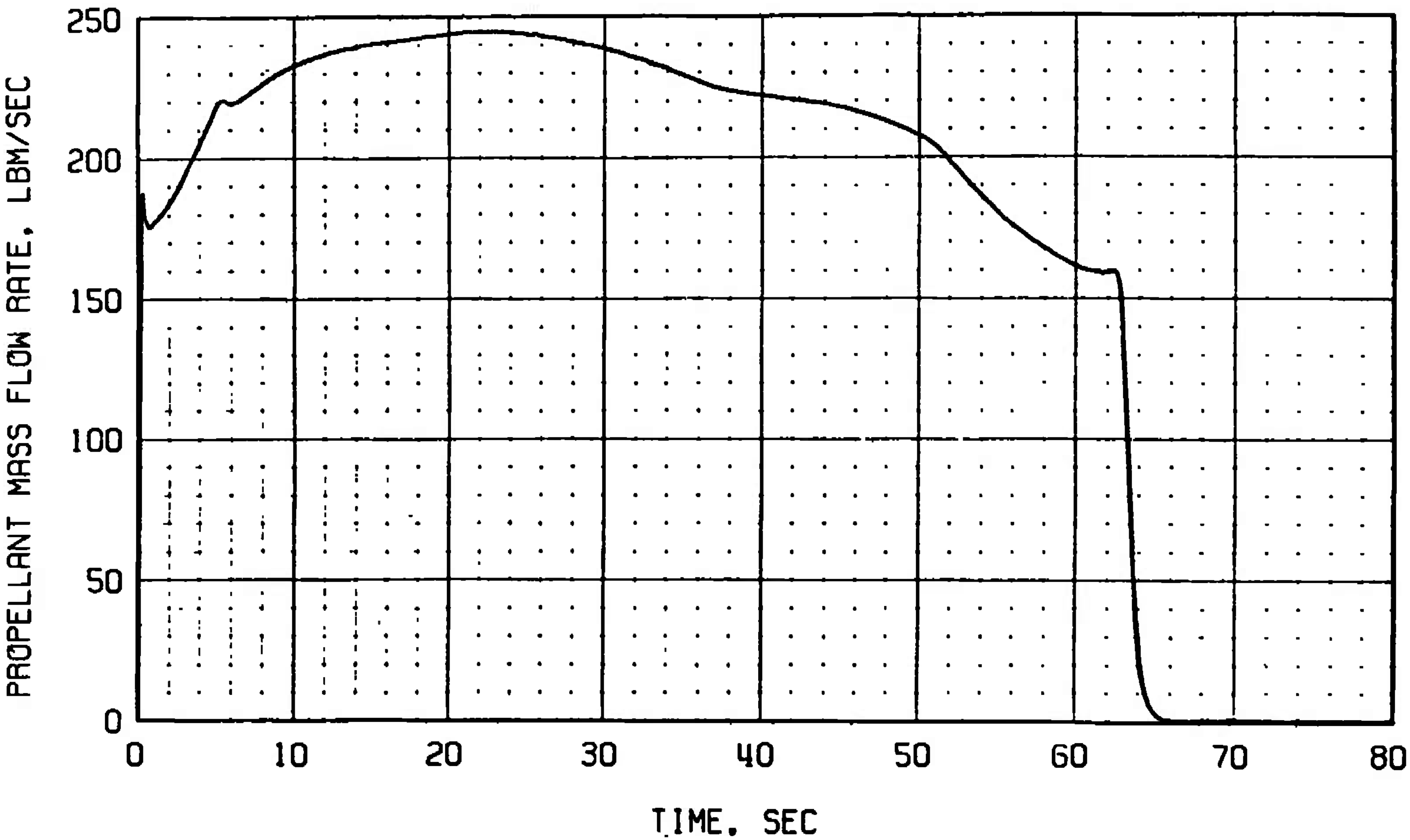


Fig. 15 Propellant Exhaust Mass Flow Rate

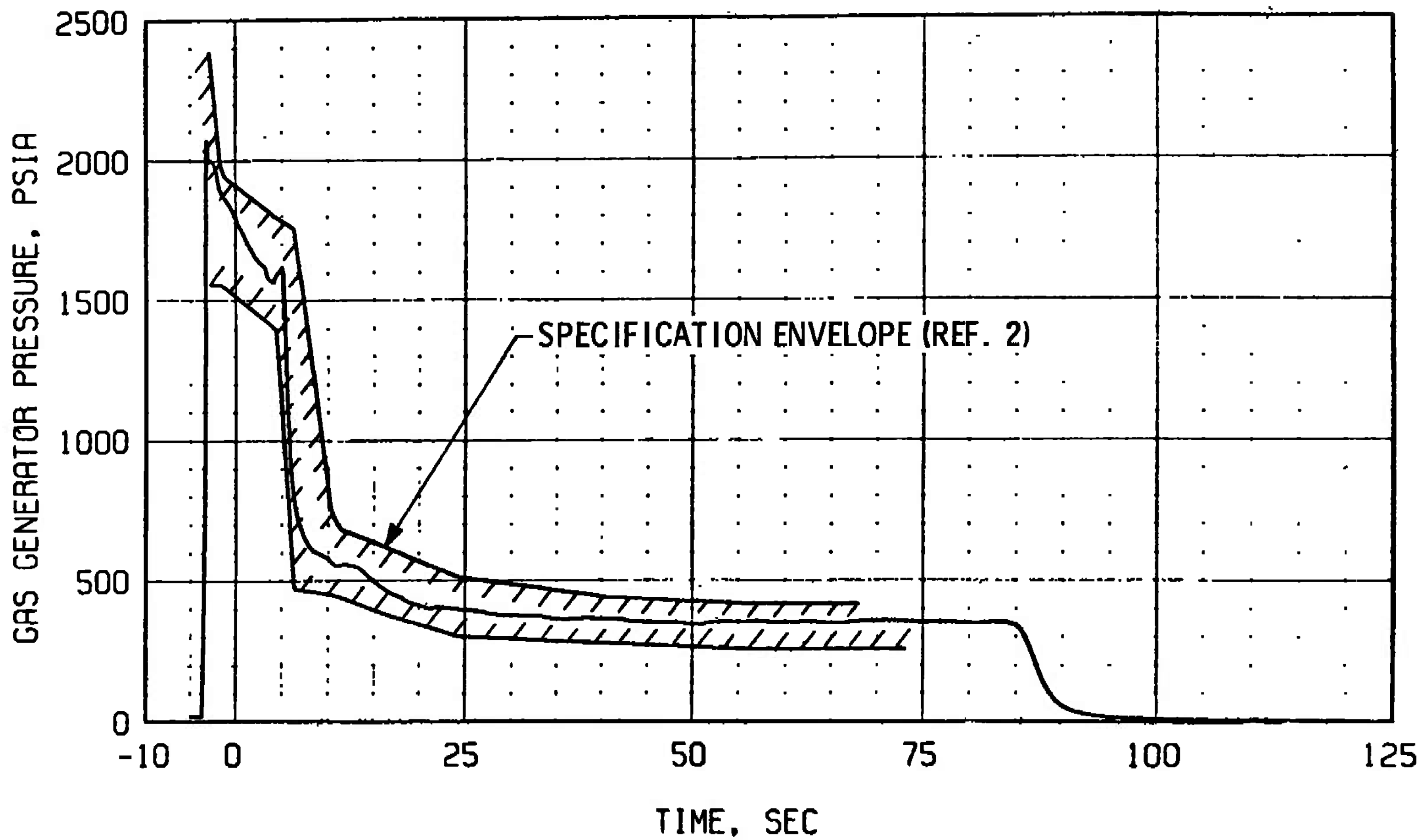


Fig. 16 Roll Control Gas Generator Pressure and Specification Envelope

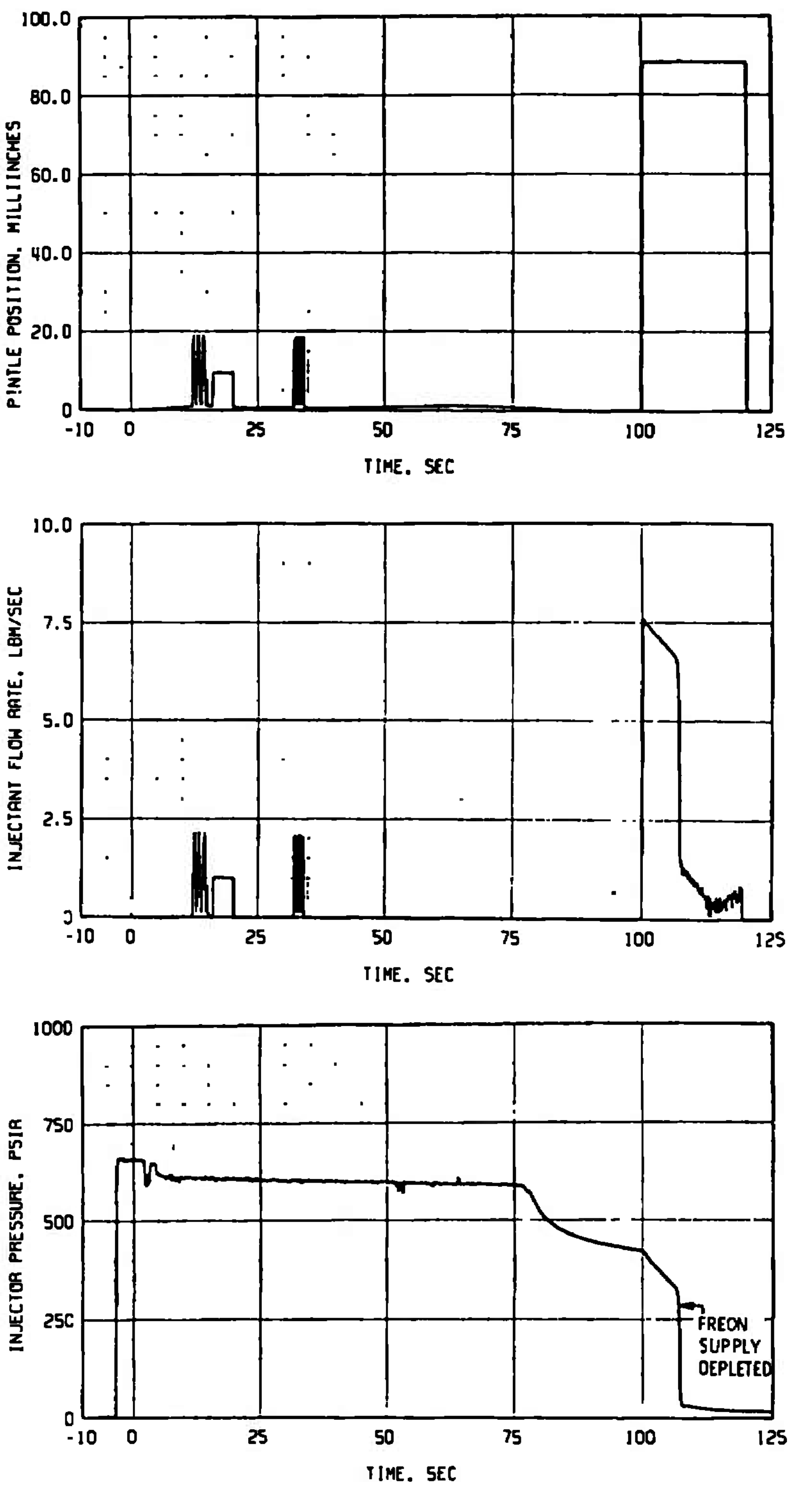


Fig. 17 Liquid-Injection Thrust Vector Control Data Summary for Liquid-Injector Valve 1 (0 deg)

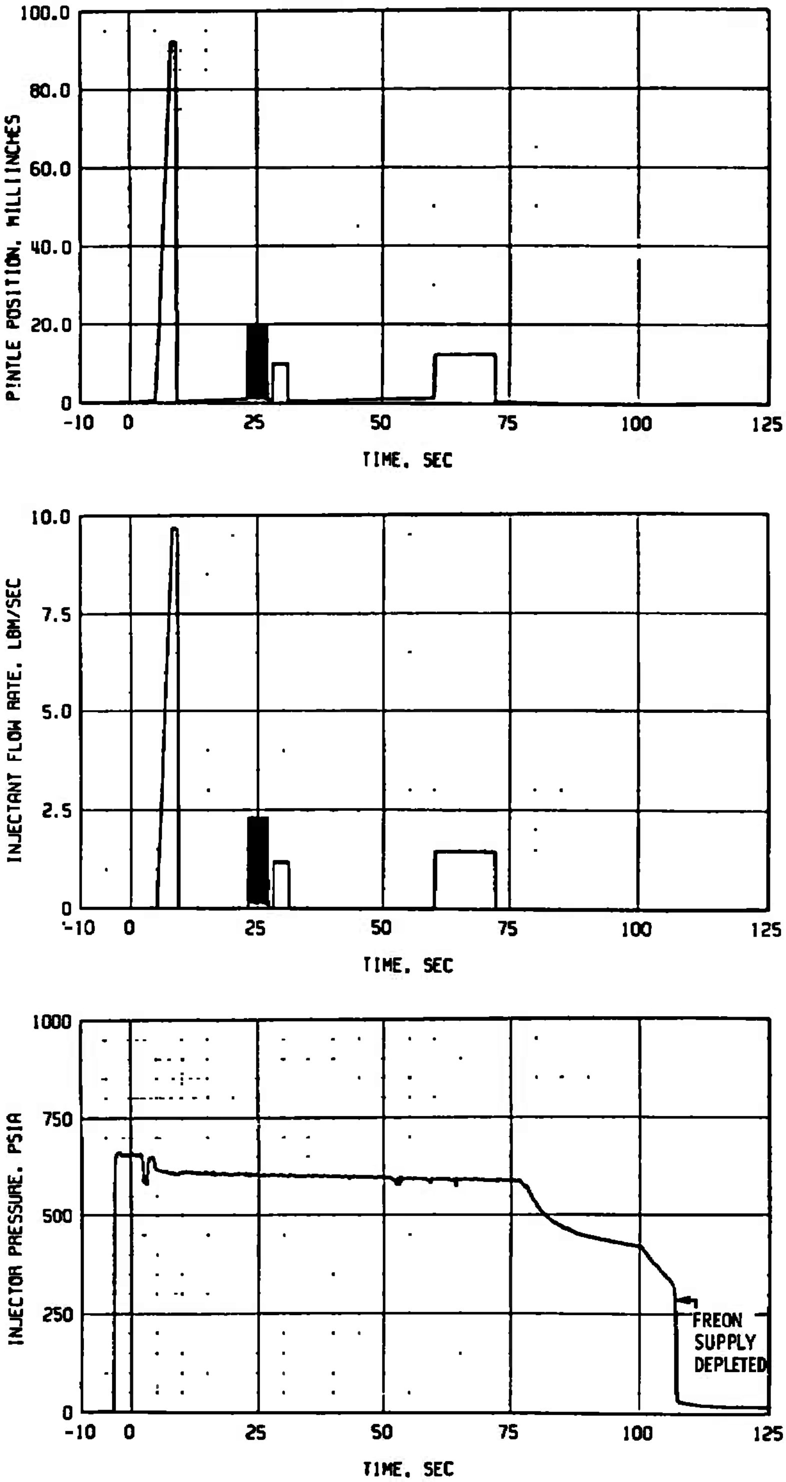


Fig. 18 Liquid-Injection Thrust Vector Control Data Summary for Liquid-Injector Valve 2 (90 deg)

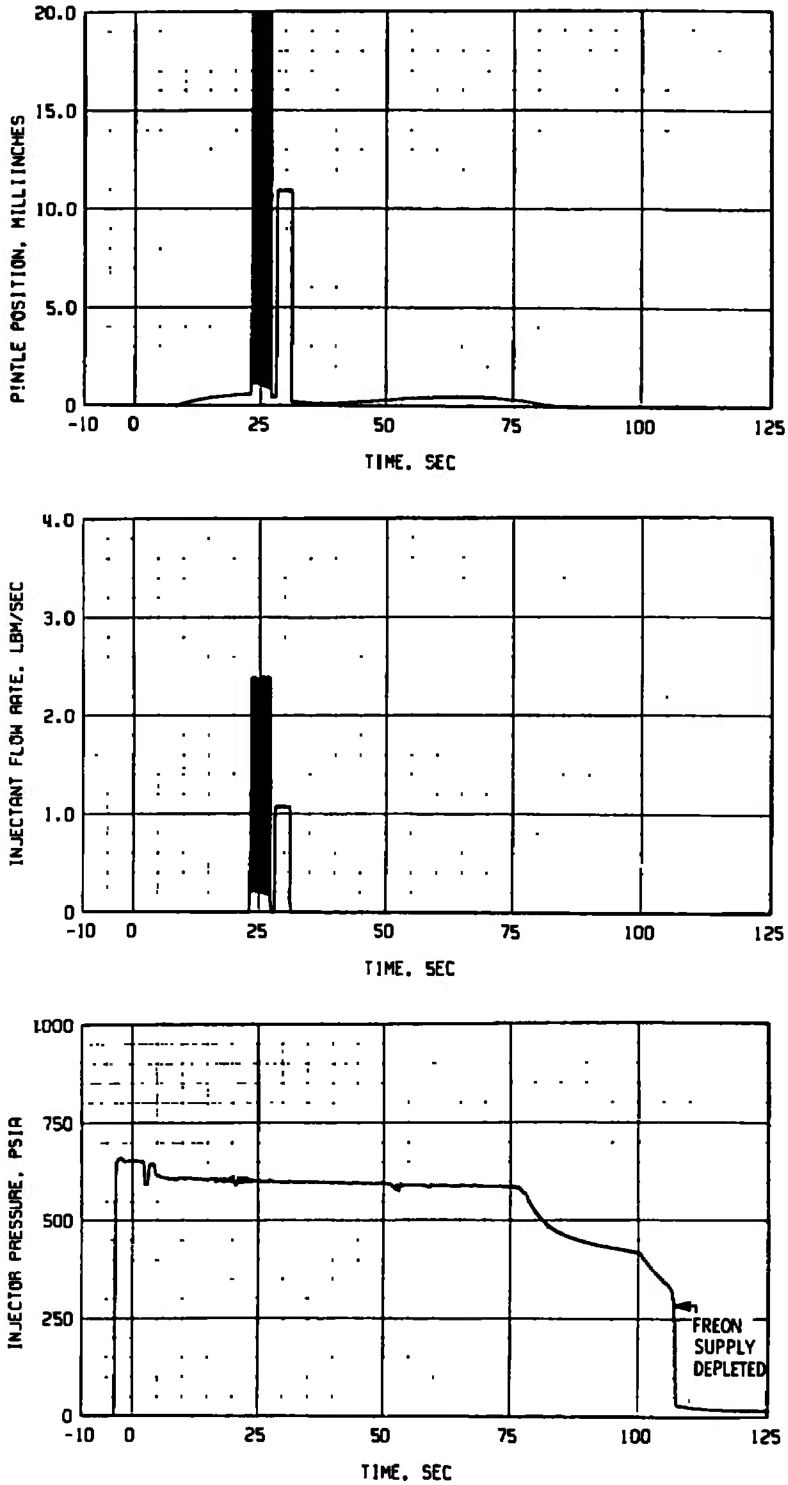


Fig. 19 Liquid-Injection Thrust Vector Control Data Summary for Injector Valve 3 (180 deg)

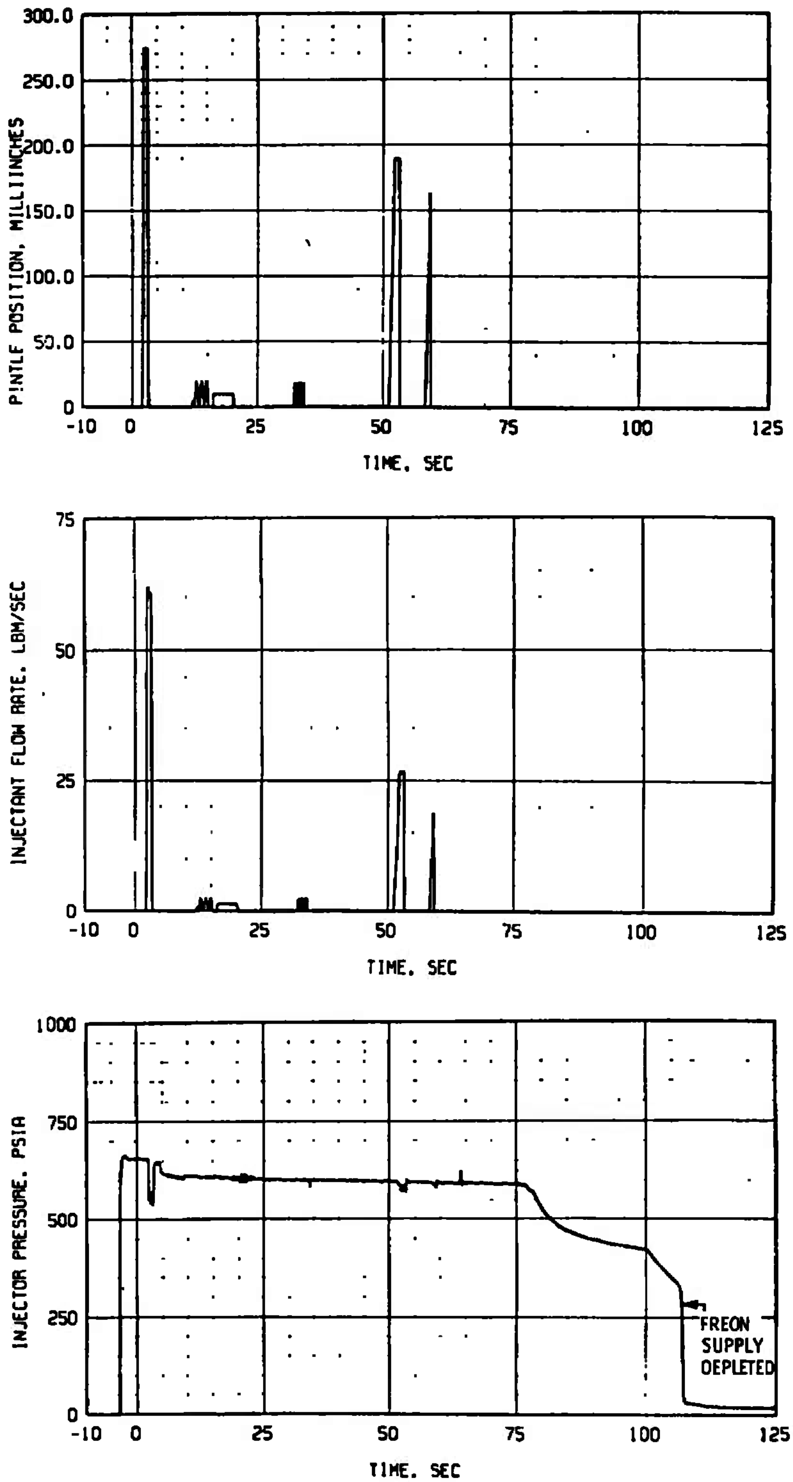


Fig. 20 Liquid-Injection Thrust Vector Control Data Summary for Injector Valve 4 (270 deg)

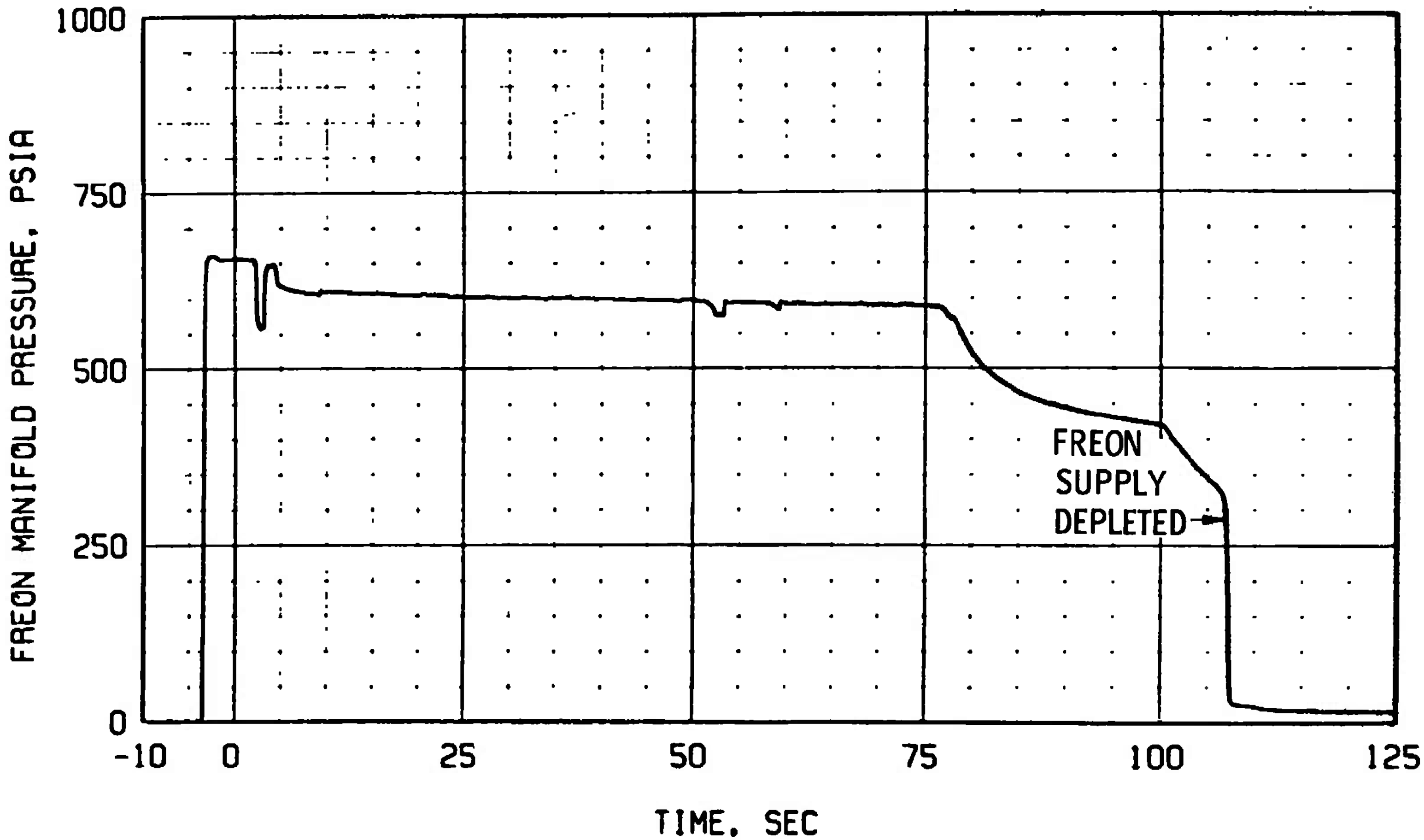


Fig. 21 Freon Manifold Pressure

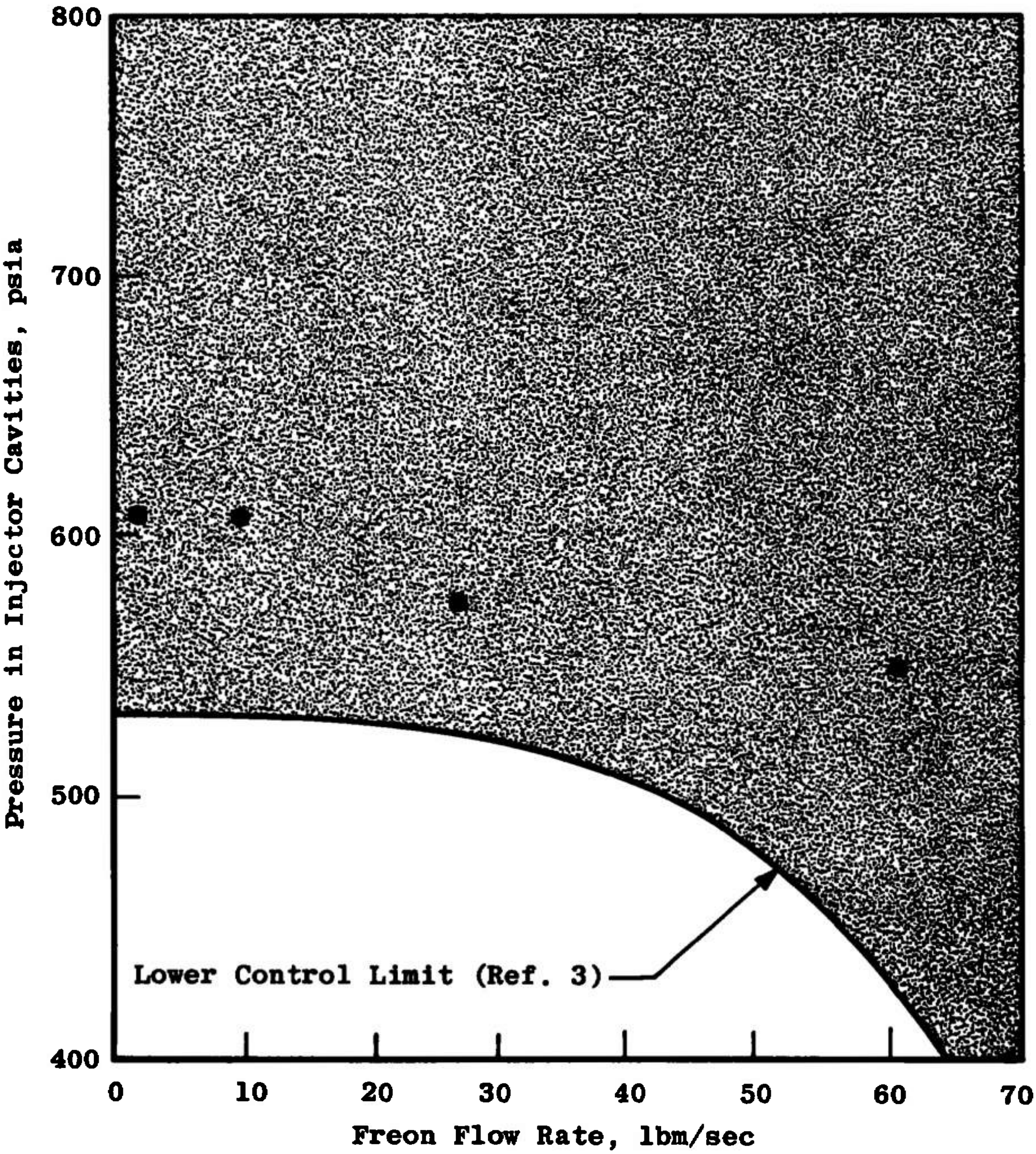


Fig. 22 Pressure Injector Cavities versus Freon Flow Rate

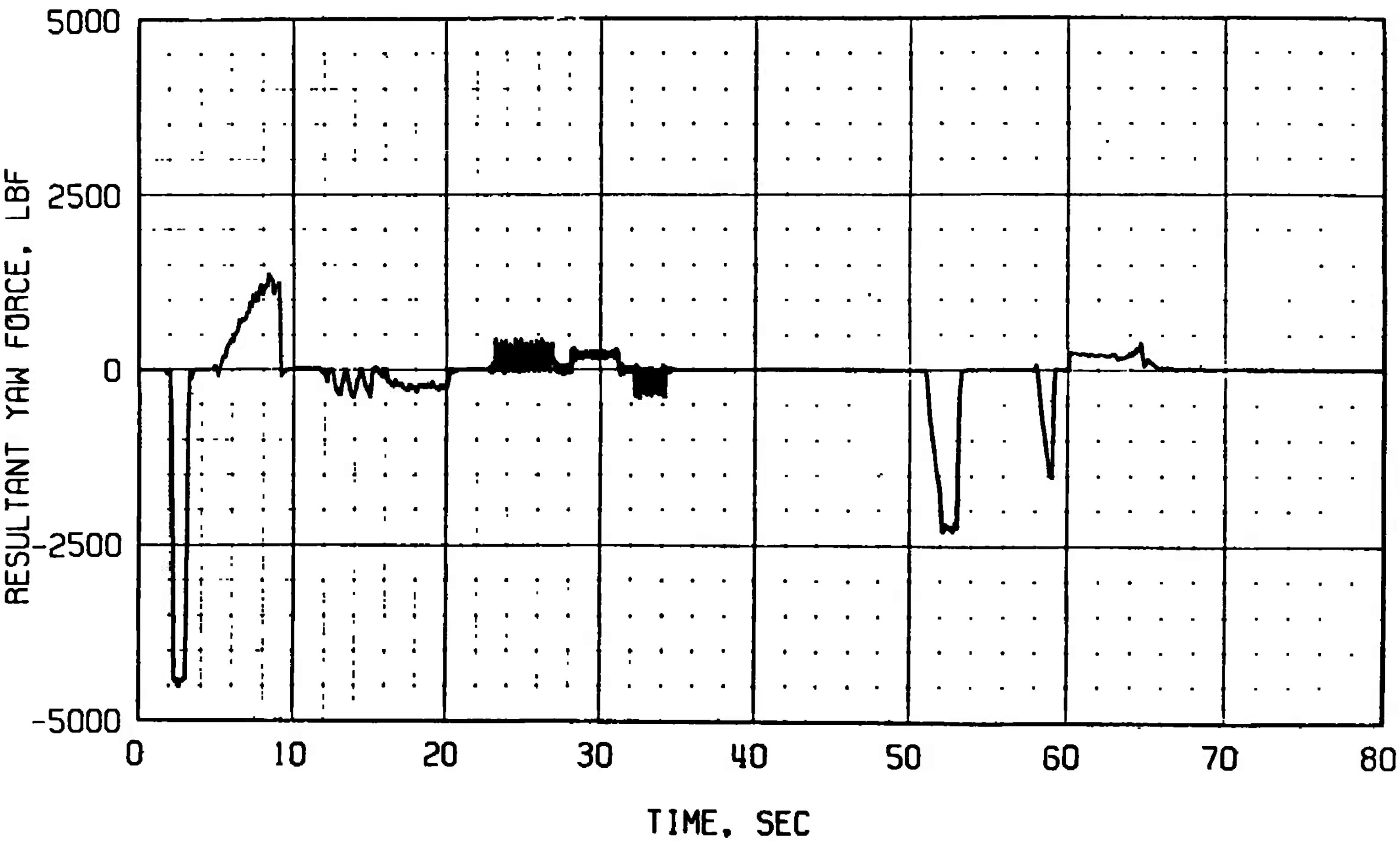
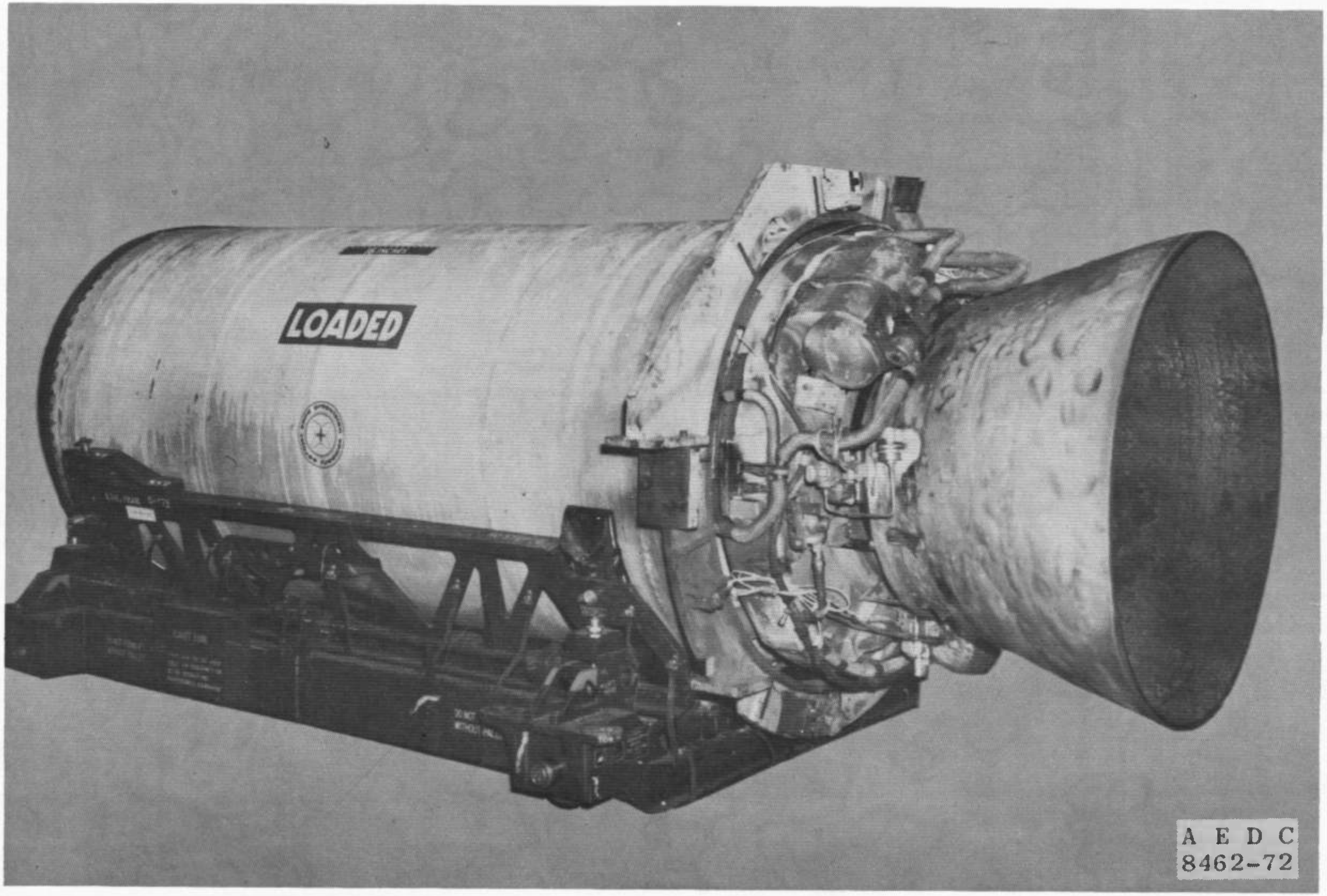


Fig. 23 Resultant Yaw Force



a. Overall View of Motor, Postfire
Fig. 24 Test Article, Postfire

b. View of Nozzle
Fig. 24 Concluded

TABLE I
TEST ARTICLE INFORMATION SUMMARY

	Part Number	Serial Number	Vendor
Rocket Motor Assembly	384078-49H	PQA 6-60	ASPC
Chamber and Support	382025-79N	7000251	AGC-Downey
Chamber Insulated	383550-59G	7000251	ASPC
Chamber Assembly, Loaded	384744-29G	7000251	ASPC
Nozzle	384023-9K	7001256	ASPC-Downey
Nozzle Exit Cone	382064-89L	7013312	Swedlow
Motor Igniter	383617-89G	2027850	ASPC
Motor Igniter Safe/Arm	KR80000-09P	0B26724	Bulova
LITVC	1107481-63BB	AAB-1743	ASPC
Gas Generator	4381000-1K	7007079	Olin Mathieson
TVC Igniter	4421000-5K	7015228	Olin Mathieson
Relief Valve	612988- C	7010268	Vickers, Inc.
Roll Control	1107506-29X		ASPC
Gas Generator	4361000-3N	7007151	Olin Mathieson
RC Igniter	4421000-5K	7015227	Olin Mathieson
Arm/Disarm Switch	7300-11AG	AXO-2344	Rucker Precision
107° RC Subassembly			
Valve and Nozzle Assembly	1107071-23N	BAR-5773	ASPC
Roll Control Valve	206335-1J	7010420	Philco Corp.
Roll Control Nozzle	1111400-1B	0000725	ASPC
Roll Control Nozzle	1111400-2B	0000736	ASPC
287° RC Subassembly			
Valve and Nozzle Assembly	1107071-23N	BAR-5756	ASPC
Roll Control Valve	206335-1J	7010397	Philco Corp.
Roll Control Nozzle	1111400-1B	0000737	ASPC
Roll Control Nozzle	1111400-2B	0000782	ASPC
Pressure Transducers			
Motor Chamber	366480-F	9816	Statham
Freon Manifold	366557-3G	9959	Statham
Roll Control Gas Generator	366557-1G	9918	Statham
LITVC System Servo-injector Valves (Model 50-275D)			
Position 1 (0°)	010-42964-A	161	MOOG, Inc.
Position 2 (90°)	010-42964-A	162	MOOG, Inc.
Position 3 (180°)	010-42964-A	163	MOOG, Inc.
Position 4 (270°)	010-42964-A	164	MOOG, Inc.

TABLE II
INSTRUMENTATION SUMMARY

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	EVENT-VOLTAGE	V DC						
EFS-1	MAIN MOTOR IGNITION	0 TO 28			X	X	X	
EFS-2	MAIN MOTOR IGNITION	0 TO 28			X	X	X	
EFS-3	LITVC IGNITION	0 TO 28			X		X	
EFS-4	LITVC IGNITION	0 TO 28			X		X	
EFS-5	ROLL CONTROL IGNIT.	0 TO 28			X		X	
EFS-6	ROLL CONTROL IGNIT.	0 TO 28			X		X	
	EVENT	V DC						
ES-1	INJ. VALVE #1 COMM.	0 TO 5			X		X	
ES-2	INJ. VALVE #2 COMM.	0 TO 5			X		X	
ES-3	INJ. VALVE #3 COMM.	0 TO 1			X		X	
ES-4	INJ. VALVE #4 COMM.	0 TO 14			X		X	
ERCV-1	RC COMMAND VOLTAGE	-30 TO 30			X		X	
ERCV-2	RC COMMAND VOLTAGE	-30 TO 30			X		X	
	FORCE	LBF		LBF				
FY-1	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000	X		X	
FY-2	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000	X		X	
FY-5	AXIAL THRUST	0 TO 80000	STRAIN GAGE	-100000 TO 100000		X		
FZA-1	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000	X		X	
FZA-2	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000	X		X	
FZA-3	AFT YAW	-6000 TO 6000	STRAIN GAGE	6000 TO -6000		X		
FZF-1	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000	X		X	
FZF-2	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000	X		X	
FZF-3	FORWARD YAW	-2000 TO 2000	STRAIN GAGE	6000 TO -6000		X		
	EVENT-CURRENT	AMP						
IFS-1	MAIN MOTOR IGNITION	0 TO 10			X		X	
IFS-2	MAIN MOTOR IGNITION	0 TO 10			X		X	
IFS-3	LITVC IGNITION	0 TO 10			X		X	
IFS-4	LITVC IGNITION	0 TO 10			X		X	
IFS-5	ROLL CONTROL IGNIT.	0 TO 10			X		X	
IFS-6	ROLL CONTROL IGNIT.	0 TO 10			X		X	
IRCV-1	RC VALVE #1 COMMAND	0 TO 2.0			X		X	
IRCV-2	RC VALVE #2 COMMAND	0 TO 2.0			X		X	

TABLE II (Concluded)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	POSITION	MILS		MILS				
LINJ-1	PINTLE VALVE #1	0 TO 100	LVDT	0 TO 300	X		X	
LINJ-2	PINTLE VALVE #2	0 TO 100	LVDT	0 TO 300	X		X	
LINJ-3	PINTLE VALVE #3	0 TO 20	LVDT	0 TO 300	X		X	
LINJ-4	PINTLE VALVE #4	0 TO 275	LVDT	0 TO 300	X		X	
LRCV-1	ROLL CONTROL VALVE 1	0 TO 6 V DC	LVDT	0 TO 6 V DC	X		X	
LRCV-2	ROLL CONTROL VALVE 2	0 TO 6 V DC	LVDT	0 TO 6 V DC	X		X	
	PRESSURE	PSIA		PSIA				
PA-1	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X		X	
PA-2	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X	X	X	
PA-5	TEST CELL	0 TO 15	STRAIN GAGE	0 TO 15	X			
PC-1	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X		X	
PC-2	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X	X	X	
PHC	HYDRAULIC SUPPLY	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PI-1	IGNITER	0 TO 1500	STRAIN GAGE	0 TO 1500	X	X	X	
PINJ-1	INJECTOR VALVE #1	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-2	INJECTOR VALVE #2	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-3	INJECTOR VALVE #3	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PINJ-4	INJECTOR VALVE #4	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PMF-4	FREON MANIFOLD	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PRCGG	ROLL CONTROL GAS GEN	0 TO 2500	STRAIN GAGE	0 TO 2500	X		X	
PRCNI-1	ROLL CONTROL NOZ. #1	-500 TO 500	STRAIN GAGE	2000 TO -2000	X		X	
PRCNI-2	ROLL CONTROL NOZ. #2	-500 TO 500	STRAIN GAGE	2000 TO -2000	X		X	
	TEMPERATURE	DEG. F		DEG. F				
TA-1	AMBIENT TEST CELL	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TA-2	AMBIENT TEST CELL	0 TO 350	C/A, TYPE K	-300 TO 2500	X			
TMF-1	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-2	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-3	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TMF-4	FREON MANIFOLD	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TRCGG	ROLL CONTROL GAS GEN	0 TO 1000	C/A, TYPE K	-300 TO 2500	X			

TABLE III
POSTFIRE NOZZLE INSPECTION

Degrees	Throat Diameter, in.	Exit Diameter, in.
0	9.558	47.760
30	9.524	47.825
60	9.526	47.780
90	9.550	47.800
120	9.558	47.770
150	9.548	47.700
Average, in.	9.544	47.7725
Area, sq in.	71.540	1792.44

TABLE IV
BALLISTIC PERFORMANCE SUMMARY OF LGM-30G STAGE II PRODUCTION QUALITY ASSURANCE MOTORS FIRED AT AEDC

Motor	AEDC TR Number	Date Fired		Propellant Temperature, °F	Average Altitude, ft	Ignition Delay, msec	TA, sec	Average FTSMUVAC, lbf	Average PC, psia	Average CFVAC	IV, lbf-sec	ISPV, lbf-sec/lbm
PQA6-48	71-86	January	1971	64	99,000	104	64.82	60,919	463	1 80	3,948,800	287.17
PQA6-49	71-145	April	1971	67	98,000	105	64.55	61,175	465	1 80	3,948,834	287.41
PQA6-50	71-184	June	1971	70	96,000	100	63.62	62,160	473	1.799	3,954,615	287.41
PQA6-51	71-211	July	1971	69	97,000	98	63.78	61,844	468	1.802	3,944,390	287.18
PQA6-52	71-268	October	1971	67	99,000	133	63.98	61,631	469	1.804	3,943,150	287.44
PQA6-53	72-12	November	1971	67	99,000	103	65.22	60,631	460	1.797	3,954,632	287.61
PQA6-54	72-43	February	1972	64	99,000	111	66.05	59,729	455	1.794	3,945,102	287.04
PQA6-55	72-79	March	1972	67	99,000	129	64.64	61,028	464	1.803	3,944,843	286.88
PQA6-56	72 103	May	1972	68	100,000	112	62.90	62,680	479	1.802	3,942,566	287.04
PQA6-57	72-157	July	1972	70	99,000	110	65.81	59,895	455	1.797	3,941,679	286.95
PQA6-58	73-6	September	1972	68	98,000	110	64.36	61,321	466	1.799	3,946,595	287.16
PQA6-59	73-4	October	1972	67	98,000	118	63.92	61,780	470	1.800	3,948,961	287.60
PQA6-60	73-41	November	1972	67	98,000	109	64.25	61,488	469	1.797	3,950,581	287.54

TABLE V
SUMMARY OF MOTOR PERFORMANCE

	ACTUAL	SPECIFICATION LIMITS MINIMUM	SPECIFICATION LIMITS MAXIMUM	PREDICTED AT 80 DEG F. *
GENERAL INFORMATION				
MOTOR S/N	PQA6-60			
MODEL NUMBER	SR19-AJ-1			
DATE FIRED	11-27-72			
DATE CAST	09-20-72			
GROSS MOTOR WEIGHT, LBM *	15516.4		15601	
MANUFACTURER'S STATED PROPELLANT WEIGHT, LBM *	13744.2	13680		
USEFUL PROPELLANT WEIGHT, LBM	13739.2			
SYSTEM MASS FRACTION *	0.885	0.884		
PREFIRE NOZZLE THROAT AREA, SQ. IN.	73.002			
AVERAGE NOZZLE THROAT AREA, SQ. IN.	73.284			
PREFIRE NOZZLE EXIT AREA, SQ. IN.	1806.84			
PREFIRE PROPELLANT BULK TEMPERATURE, DEG F.	67			
MOTOR PREFIRE CENTER OF GRAVITY *				
AFT OF FORWARD SKIRT, IN.	55.277	53.2	56.8	
RADIAL FROM MOTOR LONGITUDINAL CENTERLINE, IN.	0.052		0.150	
X AXIS	116.066			
Y AXIS	100.015			
Z AXIS	99.955			
ALTITUDE				
GAS GENERATOR IGNITION, FT.	102000			
MAIN MOTOR IGNITION, FT.	96000			
AVERAGE DURING ACTION TIME, FT.	98000			
BALLISTIC PERFORMANCE				
FORCE				
MAXIMUM MEASURED AXIAL				
AT FIRING TEMPERATURE, LBF	70359			
ADJUSTED TO 80 DEG. F., LBF	71280			
MAXIMUM UNAUGMENTED VACUUM AXIAL				
AT FIRING TEMPERATURE, LBF	70555			
ADJUSTED TO 80 DEG. F., LBF	71478			
AVERAGE MEASURED AXIAL DURING ACTION TIME				
AT FIRING TEMPERATURE, LBF	61298			
ADJUSTED TO 80 DEG. F., LBF	62100			
AVERAGE UNAUGMENTED VACUUM AXIAL DURING ACTION TIME				
AT FIRING TEMPERATURE, LBF	61488	53900	64000	
ADJUSTED TO 80 DEG. F., LBF	62292	54600	64800	62300
IMPULSE				
MEASURED TOTAL DURING ACTION TIME				
INCLUDING THRUST AUGMENTATION, LBF-SEC.	3938377			
VACUUM TOTAL DURING ACTION TIME				
INCLUDING THRUST AUGMENTATION	3959167			
EXCLUDING THRUST AUGMENTATION	3950581	3907000		3950000
SPECIFIC DURING ACTION TIME				
STANDARD (SISP10), LBF-SEC./LBM	249.56			
VACUUM EXCLUDING THRUST AUGMENTATION, LBF-SEC./LBM	287.54			287.5
MEASURED, LBF-SEC./LBM	286.65			
PERCENT OF VACUUM TOTAL DIRECTLY MEASURED	99.47			

TABLE V (Continued)

	ACTUAL	SPECIFICATION LIMITS MINIMUM	MAXIMUM	PREDICTED AT 80 DEG F. *
PRESSURE				
MAXIMUM CHAMBER DURING IGNITION TRANSIENT, PSIA	460		570	
MAXIMUM NOZZLE STAGNATION DURING IGNITION TRANSIENT, PSIA	415			
MAXIMUM CHAMBER RISE RATE, PSIA/SEC.	11206			
AVERAGE CHAMBER DURING ACTION TIME				
AT FIRING TEMPERATURE, PSIA	469			
ADJUSTED TO 80 DEG. F., PSIA	475			
AVERAGE NOZZLE STAGNATION DURING ACTION TIME				
AT FIRING TEMPERATURE, PSIA	467			
ADJUSTED TO 80 DEG. F., PSIA	473			471
MAXIMUM CHAMBER				
AT FIRING TEMPERATURE, PSIA	538		570	
ADJUSTED TO 80 DEG. F., PSIA	545			551
CHAMBER INTEGRAL DURING ACTION TIME, PSIA-SEC.	30123			
NOZZLE STAGNATION INTEGRAL DURING ACTION TIME, PSIA-SEC.	30003			
AVERAGE IGNITER, PSIA	1031	840	1217	
INTEGRAL OF IGNITER, PSIA-SEC.	276.4	250	317	
MAXIMUM IGNITER, PSIA	1102		1476	
TIME				
ACTION				
AT FIRING TEMPERATURE, SEC.(TA)	64.25			
ADJUSTED TO 80 DEG. F., SEC.	63.42			63.4
IGNITION DELAY, MSEC. (TO PC=371 PSIA)	109		250	
AT MAXIMUM CHAMBER PRESSURE, SEC.	20.97			
IGNITER DELAY MSEC. (TO PI=750 PSIA)	11.0		18	
IGNITER BURNOUT, MSEC.	278.0			
IGNITER ACTION, MSEC.	267.0			
VACUUM THRUST DECAY FROM 41000 TO 2000 LBF AT 80 DEG. F., SEC.	1.80	1.48	3.54	
AVERAGE UNAUGMENTED VACUUM THRUST COEFFICIENT	1.797			
AVERAGE MEASURED THRUST COEFFICIENT	1.792			
MISCELLANEOUS				
MASS FLOW COEFFICIENT	0.006251			
CHARACTERISTIC EXHAUST VELOCITY, FT/SEC.	5149			
LIQUID INJECTION THRUST VECTOR CONTROL SYSTEM PERFORMANCE				
FORCE				
AVERAGE RESULTANT YAW DURING FULL-OPEN COMMAND FROM 2 TO 3 SEC., LBF	4428	3800		
MAXIMUM YAW 0.250 TO 3.0 SEC., LBF	4573			
MINIMUM YAW 2 TO 3 SEC., LBF	4283			
AVERAGE RESULTANT YAW DURING COMMAND FROM 52 TO 53 SEC., LBF	2257			
PRESSURE				
AVERAGE MAXIMUM OF FOUR INJECTOR CAVITIES AND FREON MANIFOLD				
FROM TGG + 0.88 TO TGG + 6.4 SEC., PSIA	666		713	
FROM TGG + 6.4 TO TA, SEC., PSIA	650		680	
MINIMUM INJECTOR CAVITY AT FULL FLOW, PSIA	526			

TABLE V (Concluded)

	ACTUAL	SPECIFICATION LIMITS MINIMUM	SPECIFICATION LIMITS MAXIMUM	PREDICTED AT 80 DEG F.
INJECTOR CAVITY AT 71.8, SEC.				
INJECTOR 1, PSIA	592			
INJECTOR 2, PSIA	589			
INJECTOR 3, PSIA	589			
INJECTOR 4, PSIA	591			
FREON MANIFOLD, PSIA	590			
MAXIMUM AT AN INJECTOR AFTER TGG + 0.68 SEC., PSIA	667			
MINIMUM AT AN INJECTOR AFTER TGG + 0.85 SEC., PSIA	526			
AVERAGE MAXIMUM INJECTOR PRESSURE AT NO FLOW, PSIA	666			
AVERAGE MINIMUM INJECTOR PRESSURE AT NO FLOW, PSIA	591			
MAXIMUM AT FREON MANIFOLD AFTER TGG + 0.88 SEC., PSIA	663			
TIME				
FROM TGG IGNITION UNTIL FIRST INDICATION OF PRESSURE IN EACH INJECTOR				
INJECTOR 1, MSEC.	100		880	
INJECTOR 2, MSEC.	90		880	
INJECTOR 3, MSEC.	105		880	
INJECTOR 4, MSEC.	95		880	
FROM TGG IGNITION UNTIL 500 PSIA FREON TANK PRESSURE, MSEC.	210		950	
FROM TGG IGNITION UNTIL MAXIMUM PRESSURE AT AN INJECTOR, SEC.	1.30			
FROM TGG IGNITION UNTIL MINIMUM PRESSURE AT AN INJECTOR, SEC.	6.10			
FROM TGG IGNITION UNTIL MAXIMUM FREON MANIFOLD PRESSURE, SEC.	1.16			
FROM TGG IGNITION UNTIL 500 PSIA IN LAST INJECTOR CAVITY, MSEC.	210			
OF MAXIMUM YAW FORCE FROM 0.250 TO 3.0 SEC.	2.72			
RESULTANT THRUST VECTOR ANGLE FROM 52 TO 53 SEC., DEG.	2.31	2.00		
TOTAL INJECTANT PROGRAMMED AND EXPENDED TO 72 SEC., LBM	179			
TOTAL INJECTANT EXPENDED UNTIL FREON SUPPY DEPLETED, LBM	227			
MAXIMUM THRUST VECTOR ANGLE FROM 52 TO 53 SEC., DEG.	2.45			
ROLL CONTROL SYSTEM PERFORMANCE				
PRESSURE				
MAXIMUM ROLL CONTROL GAS GENERATOR, PSIA	2091			
MINIMUM ROLL CONTROL GAS GENERATOR FROM TGG + 3.7 TO TGG + 8.2 SEC.	1568			
MAXIMUM ROLL CONTROL GAS GENERATOR FROM TGG + 3.7 TO TGG + 10.2 SEC.	1791			
AT TGG + 10.2 SEC.	741			
AT TGG + 28.0 SEC.	398			
AT TGG + 60.0 SEC.	355			
AT TGG + 75.0 SEC.	361			
TIME				
ROLL CONTROL VALVE RESPONSE				
NULL TO 90 PERCENT HARDOVER, MSEC.	15		35	
HARDOVER TO 10 PERCENT NULL, MSEC.	16		50	
HARDOVER TO 90 PERCENT HARDOVER, MSEC.	19		50	
FROM TGG UNTIL 1560 PSIA IN ROLL CONTROL GAS GENERATOR, MSEC.	240		720	
FROM TGG IGNITION UNTIL MAXIMUM ROLL CONTROL GAS GENERATOR PRESSURE, SEC.	0.35			
FROM TGG IGNITION UNTIL MINIMUM PRCGG FROM TGG+3.7 TO TGG+8.2 SEC., SEC	7.62*			
FROM TGG IGNITION UNTIL MAXIMUM PRCGG FROM TGG+3.7 TO TGG+10.2 SEC., SEC.	3.70			
GAS GENERATOR BURN DURATION, SEC.	86.59			
TORQUE				
CAPACITY AT TGG+7.7 SEC.	430			
CAPACITY AT TGG+15.7 SEC.	154			
CAPACITY AT TGG+72.4 SEC.	98			

* FROM MOTOR LOG BOOK

TABLE VI
MOTOR TEMPERATURE-CONDITIONING LOG

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
11/17/72	82	62	Transportation Van	No record	No record	In transit
11/18/72	82	72				
11/19/72	70	66				
11/20/72	69	65				Unloaded at Rocket Preparation Area at 0900 hr; exposed to 47°F for 3 hr
11/20/72	68	66	Rocket Preparation Area	42	37	
11/21/72	78	66		37	22	
11/22/72	78	67		24	21	Moved to test cell at 1630 hr; exposed to 37°F for 60 min
11/22/72	66	66	Test Cell	40	38	
11/23/72	68	64		40	28	
11/24/72	66	63		49	37	
11/25/72	67	66		54	43	
11/26/72	68	66		42	36	
11/27/72	68	66		58	36	Test cell evacuated to altitude conditions at 2125 hr; motor fired at 2256 hr

TABLE VII
ROLL CONTROL DUTY CYCLE

Time, sec*	Command	Frequency, Hz
0 – 2	Hardover CCW	–
2 – 3	Null	–
3 – 4	Hardover to Hardover	10
4 – 5	Null	–
5 – 6	Null to Hardover CCW	10
6 – 7	Null	–
7 – 8	Null to Hardover CW	10
8 – 10	Hardover CCW	–
10 – 11	Hardover to Hardover	10
11 – 12	Null	–
12 – 15	Null to Hardover CW	10
15 – 18	Null to Hardover CCW	10
18 – 21	Hardover to Hardover	10
21 – 24	Null	–
24 – 27	Hardover CCW	–
27 – 30	Null to Hardover CCW	10
30 – 33	Null to Hardover CW	10
33 – 36	Hardover to Hardover	10
36 – 39	Null	–
39 – 42	Hardover CW	–
42 – 45	Null to Hardover CW	10
45 – 48	Null to Hardover CCW	10
48 – 51	Hardover to Hardover	10
51 – 54	Null	–
54 – 57	Hardover CCW	–
57 – 60	Null to Hardover CCW	10
60 – 63	Null to Hardover CW	10
63 – 66	Hardover to Hardover	10
66 – 69	Null	–
69 – 72	Hardover CW	–
72 – 75	Null to Hardover CW	10
75 – 78	Null to Hardover CCW	10
78 – 81	Hardover to Hardover	10
81 – 84	Null	–
84 – 87	Hardover CCW	–
87 – 120	Null	–

* Time is referenced to motor ignition (T). Gas generator is ignited at T–3.7 sec.

TABLE VIII
LIQUID-INJECTION THRUST VECTOR CONTROL DUTY CYCLE

Time, sec*	Injector 1	Injector 2	Injector 3	Injector 4
0–2	0	0	0	0
2–3	0	0	0	Full Open
3–5	0	0	0	0
5–8	0	0–10 lb/sec Ramp	0	0
8–9	0	10 lb/sec	0	0
9–12	0	0	0	0
12–15	±1 lb/sec at 1 Hz**	0	0	±1 lb/sec at 1 Hz**
15–16	0	0	0	0
16–20	1 lb/sec	0	0	1 lb/sec
20–23	0	0	0	0
23–27	0	±1 lb/sec at 3 Hz**	±1 lb/sec at 3 Hz**	0
27–28	0	0	0	0
28–31	0	1 lb/sec	1 lb/sec	0
31–32	0	0	0	0
32–34	±1 lb/sec at 7 Hz**	0	0	±1 lb/sec at 7 Hz**
34–51	0	0	0	0
51–52	0	0	0	0–28 lb/sec Ramp
52–53	0	0	0	28 lb/sec
53–58	0	0	0	0
58–59	0	0	0	0–20 lb/sec Ramp
59–60	0	0	0	0
60–72	0	1.25 lb/sec	0	0
72–99	0	0	0	0
100–120	10 lb/sec	0	0	0

* Time is referenced to motor ignition (T). Gas generator is ignited at T-3.7 sec.

** ±1 lb/sec about a 1 lb/sec constant bias wave form to be sinusoidal and out of phase with adjacent injector.

TABLE IX
LIQUID-INJECTION THRUST VECTOR CONTROL PERFORMANCE SUMMARY

NOMINAL TIME, SEC	2-3	8-9	16-20*	28-31*	52-53
START TIME (CALC)	2.415	8.230	16.285	28.250	52.230
STOP TIME (CALC)	2.910	8.910	19.905	30.905	52.915
INJECTOR NUMBER	4	2	4	2	4
SPECIFIED FLOW RATE, LBM/SEC.	FULL OPEN	10.0	1.0	1.0	28.0
ACTUAL FLOW RATE, LBM/SEC.	60.9	9.67	1.24	1.17	26.5
PINTLE POSITION, MILLIINCHES	274.57	91.97	9.98	9.76	190.35
PINTLE PRESSURE, PSIA	550.	607.	607.	602.	575.
PROPELLANT FLOW RATE, LBM/SEC.	191	229	243	239	195
INJECTOR-TO-PROPELLANT FLOW RATE RATIO	0.319	0.042	0.005	0.005	0.136
RESULTANT YAW FORCE, LBF	4428.	1226.	236.4	215.8	2257.
UNAUGMENTED VACUUM AXIAL THRUST, LBF	54829	65828	69893	68753	55934
YAW-TO-AXIAL FORCE RATIO	0.0808	0.0186	0.0034	0.0031	0.0403
JET DEFLECTION ANGLE, DEG.	4.62	1.07	0.19	0.18	2.31
RESULTANT YAW FORCE INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	73	127	191	184	85
AXIAL-THRUST AUGMENTATION, LBF	2164.	517.8	230.5	204.4	1038.
PERCENT AXIAL-THRUST AUGMENTATION	3.95	0.79	0.33	0.30	1.86
AXIAL-THRUST AUGMENTATION INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	35.5	53.5	**	**	39.2

* DURING THIS TIME PERIOD, BOTH PITCH AND YAW INJECTORS WERE OPERATING. IT WAS ASSUMED THAT EFFECTS OF SIMULTANEOUS INJECTION IN THE PITCH AND YAW PLANES WERE INDEPENDENT.

** DATA NOT PRESENTED FOR LOW FLOW STEPS.

APPENDIX III
INSTRUMENTATION CALIBRATIONS

The axial-thrust load cell was laboratory calibrated versus a force transfer standard before use during this test. These calibrations were verified to be within ±0.1 percent of the in-place deadweight calibrations in the range from 0 to 80,000 lbf. Axial-thrust data were reduced utilizing the deadweight calibrations.

Pressure transducers were calibrated in the standards laboratory using a deadweight pressure generator. Thermocouple wires were calibrated by the manufacturer with standards traceable to the National Bureau of Standards. The pressure and temperature instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using the resistance shunting technique for the pressures and the voltage substitution method for the temperatures. These calibrations were automatically selected from the control room. The various thermocouples were connected directly to the referenced temperature junction, and National Bureau of Standards standard thermocouple curves were the basis of the temperature data calibrations.

Calibrations of the LITVC injector valves were performed using the dial indicator pintle tool to physically measure the pintle positions on each servoinjector valve at the programmed command steps. Feedback voltages from the injector valves were measured and plotted against pintle position. The feedback voltage versus pintle position data were used to determine the injectant flow rates for each valve at its programmed command steps.

APPENDIX IV
UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS

1.0 INTRODUCTION

The rationale for the estimated instrument system uncertainties contained in Table IV-1 is provided in this appendix. The general approach taken in the analysis, the definition of terms, and the specific evaluation of each system are presented.

2.0 METHODOLOGY

The approach taken in this analysis follows the methodology established by the ARO Standard Test Data Measurement Uncertainty (ARO-ENGR-STD-T-4, February 1972). A review of the basic concepts and terminology is given in the following paragraphs in order to provide a better understanding of individual evaluations of the J-5 instrument systems.

The uncertainty of a measurement is defined to be the maximum difference reasonably expected between a measured value and the true value. Measurement errors have two components: fixed errors and random errors. A random error results from variations between repeated measurements and is called the precision error. The statistic, s, is an estimate of the standard deviation of a population and is called the precision index. It is calculated to estimate the precision error. The precision index is

$$s = \sqrt{\frac{\sum_{i}^{N} (x_i - \overline{x})^2}{(N - 1)}} \qquad (1)$$

where

N is the number of measurements

$\overline{x}$ is the average value of the measurement

x_i is the individual measurement

The second component of a measurement error is the constant or systematic error and is known as the bias. Each measurement of repeated measurements has the same bias. Large known biases are eliminated by calibrating the instrument, i.e., comparing the instrument to a standard and obtaining a correction. Small known biases may or may not be accounted for, depending upon the significance of the bias and the difficulty of correcting for the bias. Unknown biases are not correctable. Generally, the estimate of the limit for a bias is based upon judgment and experience.

In order to establish a single number for expressing a reasonable limit for the error of a measurement, some combination of bias and precision is required. It is recognized that it is impossible to define a rigorous statistic because the bias is an upper limit based upon judgment. The uncertainty U is established as that single number for stating an error. The uncertainty is centered about the measurement and is defined as

$$U = \pm(B + t_{0.95}\, S) \tag{2}$$

where

B is the estimated bias limit

S is the precision index

t is the 95th-percentile point for the two-tailed students "t" distribution

The "t" value is a function of the number of degrees of freedom (d.f.). For 30 or more degrees of freedom, a t value of 2 is assumed.

The uncertainty is an arbitrary substitute for a statistical confidence interval and can best be interpreted as the largest error to be expected. The coverage of U is greater than 95 percent under reasonable assumptions of the distribution of the bias.

In general, the errors in a measurement process originate from a multitude of different sources. The uncertainty of a total measurement can be established by two approaches:

(a) Determining the elemental error sources in the process and appropriately combining the errors and

(b) Determining the error of the complete system by comparison with a standard.

Since the error of a measurement process is the result of elemental error sources, a methodology for combining elemental errors is required in order to arrive at the total uncertainty U.

The bias limit B in equation (2) is calculated as

$$B = \sqrt{b_1^2 + b_2^2 + b_3^2 \text{----} b_n^2} \tag{3}$$

where

b_n is the n elemental error source

The above approach is taken because it is unreasonable to assume the unknown bias limits b_n are cumulative.

The precision error S in Equation (2) is

$$S = \sqrt{s_1^2 + S_2^2 + S_3^2 ----s_n^2} \tag{4}$$

where

s_n is the precision error in the n elemental source

The degress of freedom for S may be found by use of the Welch-Satterthwaite formula as follows:

$$\text{d.f.} = \frac{(s_1^2 + s_2^2 + s_3^2 ----s_n^2)^2}{\frac{s_1^4}{df_1} + \frac{s_2^4}{df_2} + \frac{s_3^4}{df_3} ---- \frac{s_n^4}{df_n}} \tag{5}$$

The establishment of the d.f. for S makes it possible to define the precision error of subsequent measurement processes or analyses.

The uncertainties of the J-5 instrument systems are tabulated in Table IV-1.

TABLE IV-1
ESTIMATED TOTAL UNCERTAINTY (±2 SIGMA LIMITS) OF INSTRUMENT SYSTEMS USED IN DETERMINING MOTOR PERFORMANCE

	Uncertainty, percent, full scale
Pressure Measurements[1]	± 0.44
Temperature Measurements (Thermocouples, C/A)	± 0.47
Axial-Force Measurements	± 0.13
Side-Force Measurements	± 0.45

[1]Uncertainty calculated for AEDC-supplied transducers only.

APPENDIX V
METHODS OF CALCULATION

1. FA = Average measured axial thrust including augmentation, lbf

FA = (FY-1 + FY-2)/2

where

FY-1 and FY-2 are measured axial force

2. FTSM = Average measured thrust smoothed

$$= [FA_{(i-4)} + 2FA_{(i-3)} + 3FA_{(i-2)} + 4FA_{(i-1)} + 5FA_{(i)} + 4FA_{(i+1)} + 3FA_{(i+2)} + 2FA_{(i+3)} + FA_{(i+4)}]\ 1/25$$

3. PO = Average measured chamber pressure at the forward dome, psia

PO = (PC-1 + PC-2)/2

where

PC-1 and PC-2 are measured chamber pressure. The operational pressure transducer (PC-1) data will not be used if it disagrees more than 0.5percent with the facility transducer (PC-2).

4. PALT = Average test cell pressure, psia

PALT = (PA-1 + PA-2)/2

where

PA-1 and PA-2 are measured cell pressure

5. PSN = Nozzle throat stagnation pressure, psia

PSN = PO(PSN/PO)

where

PSN/PO is an input table furnished by Aerojet-General Corporation

The above approach is taken because it is unreasonable to assume the unknown bias limits b_n are cumulative.

The precision error S in Equation (2) is

$$S = \sqrt{s_1^2 + S_2^2 + S_3^2 \cdots s_n^2} \tag{4}$$

where

s_n is the precision error in the n elemental source

The degress of freedom for S may be found by use of the Welch-Satterthwaite formula as follows:

$$\text{d.f.} = \frac{(s_1^2 + s_2^2 + s_3^2 \cdots s_n^2)^2}{\dfrac{s_1^4}{df_1} + \dfrac{s_2^4}{df_2} + \dfrac{s_3^4}{df_3} \cdots \dfrac{s_n^4}{df_n}} \tag{5}$$

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   $= [FA_{(i-4)} + 2FA_{(i-3)} + 3FA_{(i-2)} + 4FA_{(i-1)} + 5FA_{(i)} + 4FA_{(i+1)} + 3FA_{(i+2)} + 2FA_{(i+3)} + FA_{(i+4)}]\ 1/25$

3. PO = Average measured chamber pressure at the forward dome, psia

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   where

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4. PALT = Average test cell pressure, psia

   PALT = (PA-1 + PA-2)/2

   where

   PA-1 and PA-2 are measured cell pressure

5. PSN = Nozzle throat stagnation pressure, psia

   PSN = PO(PSN/PO)

   where

   PSN/PO is an input table furnished by Aerojet-General Corporation

Time, sec	PSN/PO
0.0	0.8800
0.25	0.9130
0.50	0.9240
0.75	0.9340
1.00	0.9410
1.50	0.9530
2.00	0.9620
2.50	0.9685
3.00	0.9735
3.50	0.9773
4.00	0.9805
5.00	0.9844
6.00	0.9873
7.00	0.9897
8.00	0.9915
10.00	0.9940
12.00	0.9960
14.00	0.9974
16.00	0.9985
18.00	0.9990
22.00	1.0000
End of Test	1.0000

6. ATC = Calculated throat area

a. From T to PSN = 200 psia

AT = Prefire measured throat area (furnished by Aerojet Solid Propulsion Company)

b. From PSN = 200 psia until initiation of motor tailoff (determined by engineering personnel) AT is calculated by an iteration method utilizing the following equations:

(1) FTSMUVAC = (KFVAC) (PSN) (AT) (CFVAC)

(2) $$AE/AT = \lambda \left(\frac{\gamma - 1}{2}\right)^{1/2} \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{PSN}{Pe}\right)^{1/\gamma} \left[1 - \left(\frac{Pe}{PSN}\right)^{\frac{\gamma-1}{\gamma}}\right]^{-1/2}$$

(3) $$CFVAC = \lambda\gamma^{1/2} \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2(\gamma-1)}} \left(\frac{2\gamma}{\gamma - 1}\right)^{1/2} \left[1 - \left(\frac{Pe}{PSN}\right)^{\frac{\gamma-1}{\gamma}}\right]^{1/2} + \frac{Pe}{PSN}\left(\frac{AE}{AT}\right)$$

where

KFVAC = FTSMVAC/(PSN)(AT Prefire)(CFVAC) theoretically calculated after the first injection step

Pe = Exit pressure, psia

λ = Theoretical nozzle correction factor (calculated using AGC Computer Program)

γ = Ratio of specific heats
= 1.20

a. An initial guess for Pe is taken and substituted into equation 2 to obtain AE/AT

b. This value of AE/AT is substituted into equation 3 to obtain CFVAC

c. With these values, equation 1 is solved for AT (Reference: Aerojet-General Job 603.1)

c. From initiation of tailoff to end of action time, AT is considered constant at the last valid area calculated.

7. FTSMVAC = Smoothed augmented axial thrust corrected to vacuum conditions, lbf

FTSMVAC = FTSM + PALT(AE)

where

AE = Prefire nozzle exit area

8. WDOTP = Propellant mass flow rate, lbm/sec

WDOTP = K6(PSN)(ATC)

where

K6 = $WP\text{-}5/\int_{T}^{TA} PSN\ (ATC)\ dt$

WP-5 = Manufacturer's stated propellant weight -5, lbm

= Useful propellant weight

T = Time at first indication of ignition voltage

TA = Motor action time

9. Delta FTSM = Thrust augmentation attributable to secondary injection

Thrust augmentation attributable to secondary fluid injection is calculated utilizing the vacuum corrected axial thrust to nozzle throat stagnation pressure ratio (FPRVAC), and the vacuum corrected axial thrust to pressure ratio excluding augmentation (FPRUVAC).

a. FPRVAC = FTSMVAC/PSN

FPRUVAC = FPRVAC, during periods of no injection

FPRUVAC = $X + M(t_i - t_1)$, $t_1 \leq t_i \leq t_2$, during injection periods

where

X = FPRVAC at the beginning of the injection step

M = Slope of the straight line between FPRVAC at the beginning of each injection step and FPRVAC at the end of each injection step.

t_i = Instantaneous time, sec

t_1 = Time at the beginning of each injection step, sec

t_2 = Time at the end of each injection step, sec

b. The unaugmented vacuum axial thrust (FTSMUVAC) is then calculated as follows:

FTSMUVAC = (PSN) · FPRUVAC

c. The augmentation attributable to secondary injection (Delta FTSM) is obtained by subtracting the unaugmented axial thrust from the augmented axial thrust:

Delta FTSM = FTSMVAC - FTSMUVAC

10. $\overline{\text{CFVAC}}$ = Vacuum thrust coefficient

$\overline{\text{CFVAC}}$ = FTSMUVAC/(PSN)(ATC)

11. TRC = Roll control torque, ft-lbf

TRC = C_1 (PRCGG)

where

C_1 = 0.2745 ft-lbf/psia
(supplied by Odgen Air Materiel Area)

PRCGG = Measured roll control gas generator pressure, psia

12. Temperature corrected performance data

Time (t_s) = Time (t_f)/K

Thrust (t_s) = (K) Thrust (t_f)

Pressure (t_s) = (K) Pressure (t_f)

where

$$K = e^{\pi p(t_s - t_f)}$$

πp = 0.0010

t_s = Standard propellant grain temperature (80°F)

t_f = Propellant grain temperature at ignition

13. SISP10 = Specific impulse at standard conditions (chamber pressure = 1000 psia, exhaust pressure = 14.7 psia, and optimum expansion with a 15-degree, half-angle nozzle), lbf-sec/lbm

$$\text{SISP10} = \frac{\text{ISP STD TH}}{\text{ISP VAC TH}} \text{(ISPVAC)}$$

where

ISP STD TH = Standard theoretical specific impulse at desired conditions

= 252.79 lbf-sec/lbm (given condition)

ISP VAC = Measured specific impulse at vacuum conditions, lbf-sec/lbm

ISP VAC TH = Theoretical vacuum specific impulse for a given propellant and nozzle area ratio, lbf-sec/lbm (taken from following table furnished by Aerojet-General)

Nozzle Area Ratio, A_{exit}/A_{throat}	ISP VAC TH, lbf-sec/lbm
21.1735	287.66
21.4351	287.94
21.6983	288.22
21.9631	288.50
22.2255	288.78
22.4821	289.04
22.7401	289.31
22.9996	289.57
23.2605	289.82
23.5209	290.08
23.7732	290.33
24.0269	290.58
24.2819	290.81
24.5382	291.05
24.7959	291.30

14. CW = Mass flow coefficient

$$CW = \frac{\text{useful propellant weight}}{\int_T^{TA} PSN\,(ATC)\,dt}$$

15. C* = Characteristic exhaust velocity

$$C^* = \frac{\left(\int_T^{TA} PSN\,dt/TA\right)\left(\int_T^{TA} ATC\,dt/TA\right)g}{\text{useful propellant weight}/TA}$$

16. WDOT-I = Injectant flow rate

$$\text{WDOT-I} = \text{WDOT(CAL)}\sqrt{\frac{[\text{SPG(TEST)}]\,[\Delta P(\text{TEST})]}{[\text{SPG(CAL)}]\,[\Delta P(\text{CAL})]}}$$

where

WDOT(CAL) = Input table with WDOT(CAL) as a function of pintle position

SPG(TEST)	=	Specific gravity of Freon 114B2 at the test temperature
	=	2.180 - 0.00147 (TF - 70)
TF	=	Freon temperature, °F
SPG(CAL)	=	Specific gravity of Freon 114B2 at 80°F and 600-psig injectant pressure = 2.165
ΔP CAL	=	600 psid
ΔP TEST	=	(PINJ-I) - PNE
PINJ-I	=	Injectant pressure at each injector valve as measured during the firing
I	=	1, 2, 3, and 4 designates the injector valve number
PNE	=	Input table with PNE as a function of WDOT(CAL) (furnished by Aerojet-General)

PNE versus WDOTCAL

$\dot{W}$ (lbm/sec)	PNE (psia)
0	9.5
5	15.3
10	20.8
15	26.2
20	31.3
25	35.8
30	39.3
35	40.9
40	41.3
60	41.7
80	42.1

17. ISPINJ = Yaw force injectant specific impulse

ISPINJ	=	FZRC I/WDOTFZ
FZRC	=	Resultant yaw force
WDOTFZ	=	Injectant flow rate through valve 2 or 4

18.*	FZRC/FTSMUVAC	=	Yaw to axial-force ratio
	where		
	FTSMUVAC	=	Smoothed unaugmented vacuum axial thrust
19.*	WDOTR	=	Injectant to motor flow rate ratio
	WDOTR	=	WDOT-I/WDOTP
	where		
	I	=	Valves 1, 2, 3, and 4 or a combination of these valves
20.*	AISP	=	Axial-thrust augmentation injectant specific impulse
	AISP	=	Delta FTSM/WDOT-I

*Not valid during periods of no injection

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13. ABSTRACT

LGM-30G Stage II solid-propellant rocket motor (S/N PQA6-60) was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF) on November 27, 1972, in support of the Minuteman Production Quality Assurance Test Program. Motor ballistic, liquid-injection thrust vector control system, and roll control system performances were within model specification requirements. Ignition of both the roll control and the liquid-injection thrust vector gas generators was accomplished as programmed, 3.7 sec before motor ignition at a pressure altitude of 102,000 ft. The motor was ignited at a pressure altitude of 96,000 ft. Motor ignition delay time was 109 msec. Motor action time was 64.25 sec, during which the motor produced an unaugmented vacuum total impulse of 3,950,581 lbf-sec. The unaugmented vacuum specific impulse was 287.54 lbf-sec/lbm. The liquid-injection thrust vector control and roll control systems operated as programmed throughout the firing. Postfire motor structural integrity was satisfactory with the exception that the nozzle sea-level liner had been ejected during the firing at T + 63.9 sec.

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AFSC
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